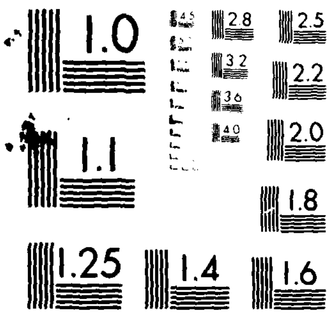
AD-A107 429   ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND WS--ETC F/G 20/14
EFFECT OF HAIL, SNOW, AND MELTING HYDROMETEORS ON MILLIMETER RA--ETC(U)
JUL 81   H K KOBAYASHI

UNCLASSIFIED   ERADCOM/ASL-TR-0092   NL

END
DATE
FILMED
12 81
DTIC



MICROCOPY RESOLUTION TEST CHART

(12) LEVEL II

ASL TR-0092

AD
Reports Control Symbol
OSD - 1366

AD A107429

EFFECT OF HAIL, SNOW, AND MELTING HYDROMETEORS ON MILLIMETER RADIO WAVES

JULY 1981

By

Herbert K. Kobayashi

DTIC
ELECTE
NOV 16 1981
S D
B

DTIC FILE COPY

Approved for public release; distribution unlimited.

US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

81 11 03 017

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

ERRATA SHEET

ASL-TR-0092
EFFECT OF HAIL, SNOW, AND MELTING HYDROMETEORS
ON MILLIMETER RADIO WAVES

Page 18 Figure 4, the numbers on the RAINDROP AND MELTED SNOWFLAKE DIAMETER D(mm) should be corrected to read: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0

Page 19 Figure 6, the numbers on the RAINDROP DIAMETER(mm) should be corrected to read: 1.0, 2.0, 3.0, 4.0

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ASL-TR-0092

2. GOVT ACCESSION NO.: AD-A107429

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): EFFECT OF HAIL, SNOW, AND MELTING HYDROMETEORS ON MILLIMETER RADIO WAVES

5. TYPE OF REPORT & PERIOD COVERED: Final Report

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): Herbert K. Kobayashi

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
US Army Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Task 1L161102B53A/C

11. CONTROLLING OFFICE NAME AND ADDRESS:
US Army Electronics Research and Development Command
Adelphi, MD 20783

12. REPORT DATE: Jul[illegible]81

13. NUMBER OF PAGES: 52

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

12 54

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric effects	Backscatter
Millimeter waves	Hail
Hydrometeors	Snow
Attenuation	Size distribution

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is a short survey intended to present the effect of solid and melting hydrometeors on millimeter radio waves. Hail and sleet were found to be more amenable to theoretical calculation and laboratory experimentation than snow because of their simpler approximations of particle shape and dielectric constant. However, field measurements on hail and sleet are scarce in comparison to snow. The most pressing need was found to be the gathering of reliable field data on the morphology and size distribution of hydrometeor

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

410663

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (cont)

particles, particularly those in a melting state where the effect on millimeter waves may exceed that of rain. These data are needed to more closely relate experimental measurement to theoretical calculation.

PREFACE

The author gratefully acknowledges the aid of Dr. Donald E. Snider of the US Army Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico; Mr. William B. Grant of the Institute for Telecommunication Sciences, Department of Commerce, Boulder, Colorado; and Ms. Vicky Schneller and the staff of the ITS/NOAA/NBS Library, Boulder, Colorado.

RE: ASL TR 0092, Classified References, Distribution Unlimited.
No change per Mr. Buck Sims, ASL/DELAS-DM-A

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Recent reviews on the atmospheric effect on millimeter waves,[1-3] including one review by the author, have reported that the literature on nonliquid hydrometeors was very scarce. However, a more thorough search during the past year has uncovered several dozen articles yielding useful quantitative data. Unlike rain, attenuation and scatter by solid and melting hydrometeors have not been reviewed to any extent although Ryde in his classic World War II report on attenuation of millimeter waves[4] allotted hail as much discussion as rain, fog, and clouds. As early as 1955, Robinson[5] wrote: ". . . moist snow produced attenuation two and a half times greater than rain of similar precipitation rate." Some reasons for this apparent neglect may be:

a. Rain is a more frequently encountered hydrometeor and has overshadowed discussion on other forms of precipitation.

b. As in rain propagation, the computer modeling needed to compare experimental data with theoretical predictions is based on meager information, particularly for melting hydrometeors.

c. Unlike clear-air and rain experiments, field measurements must be done opportunistically on short-lived phenomena during seasonal conditions usually uncomfortable for experimenters.

A computerized author/title/subject search of major data bases across the nation by the Boulder Laboratories library staff (Department of Commerce, Boulder, Colorado) yielded about 50 papers linking millimeter waves with nonliquid hydrometeors. Many of these papers featured rain as the topic of importance. For the most part, the papers fell into three categories:

a. Experimental or measured attenuation, usually with reference to theoretical calculations.

---

[1] D. M. Brown and M. B. Wells, 1978, A Literature Review of Millimeter and Submillimeter Radiation Absorption and Scatter in the Atmosphere, Final Report, ARBRL-CR-00382, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, AD A062375

[2] S. M. Kulpa and E. A. Brown, 1979, Near-Millimeter Wave Technology Base Study: Volume I - Propagation and Target/Background Characteristics, Special Report, HDL-SR-79-8, Harry Diamond Laboratories, Adelphi, MD

[3] H. K. Kobayashi, 1980, Atmospheric Effects on Millimeter Radio Waves, ASL-TR-0049, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, AD A081414

[4] J. W. Ryde and D. Ryde, 1945, Attenuation of Centimetre and Millimetre Waves by Rain, Hail, Fogs and Clouds, Report 8670, General Electric Research Laboratories, Wembley, England

[5] N. P. Robinson, 1955, "Measurements of the Effect of Rain, Snow and Fogs on 8.6 mm Radar Echoes," Proceedings IEEE, London, 203B:709

b. Theoretical or calculated attenuation and backscattering, often with reference to field measured backscattering.

c. Laboratory measurements of attenuation and backscattering with reference to theoretical calculations.

This report is presented in the sequence above. Since the decision as to whether a paper is experimental or theoretical is an arbitrary one, there is some overlap in the first two categories. There is a tendency for attenuation to be associated with one-way, point-to-point communication needs and for scatter, especially backscatter, to interest radar specialists.

EXPERIMENTAL OR MEASURED ATTENUATION

Research papers on attenuation fall into two categories:

a. Sufficient data taken to insure a graph of plotted points versus precipitation rate normally expressed as millimeters per hour equivalent rain rate.[5-10]

b. Only single values given for the occurrence of unusual weather situations.

The first category is listed in table 1 with attendant field data shown as average curves in figure 1. Snow ranging from dry to melting condition predominates, possibly because, like rain, snow is a long-lived phenomenon and an easy hydrometeor to identify. In a recent review, Kulpa and Brown found no experimental data on hail.[2]

---

[5]N. P. Robinson, 1955, "Measurements of the Effect of Rain, Snow and Fogs on 8.6 mm Radar Echoes," Proceedings IEEE, London, 203B:709

[6]Yu. S. Babkin et al, 1970, "Attenuation of Radiation at a Wavelength of 0.96 mm in Snow," Radio Engineering and Electronic Physics, 15:2171

[7]A. Nishitsuji, 1971, "Method of Calculation of Radio-Wave Attenuation in Snowfall," Electronics and Communications in Japan, 54-B:74

[8]T. Oomori and S. Aoyagi, 1971, "A Presumptive Formula for Snowfall Attenuation of Radio Waves," Electronics and Communications in Japan, 54-B:34

[9]V. G. Malinkin, A. V. Sokolov, and Ye. V. Sukhonin, 1976, "Attenuation of Signal at the Wavelength λ = 8.6 mm in Hydrometeors," Radio Engineering and Electronic Physics, 21:1

[10]W. W. Richard, J. E. Kammerer, and R. G. Reitz, 1977, "140-GHz Attenuation and Optical Visibility Measurements of Fog, Rain and Snow," Memorandum Report, ARBRL-MR-2800, Ballistics Research Laboratories, Aberdeen Proving Ground, MD

[2]S. M. Kulpa and E. A. Brown, 1979, Near-Millimeter Wave Technology Base Study: Volume I - Propagation and Target/Background Characteristics, Special Report, HDL-SR-79-8, Harry Diamond Laboratories, Adelphi, MD

TABLE 1. SNOWFALL ATTENUATION EXPERIMENTS AT MILLIMETER WAVELENGTHS

Reference Number	Year	Author(s)	Frequency (GHz)	Path Length (km)	Location	Comments
5	1955	Robinson, N.	35	15.3	Not stated (So. England?)	Dry and wet snow effect estimated
6	1970	Babkin, Y., et al	312.5	0.680	"Middle zone" of European USSR	Snowfall rate characterized
7	1971	Nishitsuji, A.	15, 35, 50	12.4	Sapporo, Japan	Wet, moist, and watery snow
8	1971	Oomori, T., et al	11, 15, 24, 48*	8.9	Sapporo, Japan	Snowfall rate
9	1976	Malinkin, V., et al	35	5.6	Moscow, USSR	Dry snow
10	1977	Richard, W., et al	140	0.725	Not stated (Maryland, USA?)	Large, moist snowflakes

*Simultaneous radio propagation on all frequencies along the same path

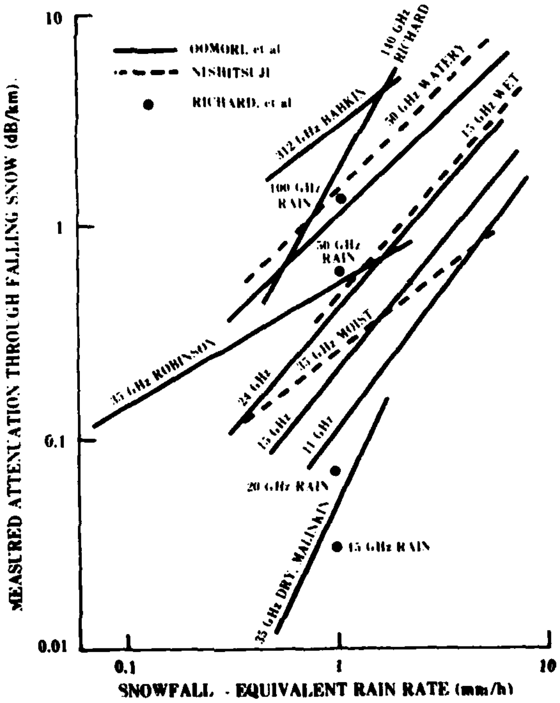


Figure 1. Measured attenuation through falling snow (further details in table 1).

Oomori and Aoyagi's comprehensive experiment[8] merits initial discussion because it entailed simultaneous frequency measurements along the same 8.9 km path, thus enabling 11, 15, 24, and 48 GHz attenuation to be assessed for the same meteorological conditions. Their data are statistically reliable for indicating trends between 10 and 50 GHz because probability distributions for attenuation and precipitation rates, averaged over short intervals, were gathered during an entire winter season. First, there is a tendency for attenuation to increase with frequency and snowfall rate.

Asari verified this tendency for the same frequencies in his theoretical paper on wet snowfall.[11] Next attenuation at the precipitation rate of 1 mm/h is consistently greater than for rain (shown as dots in figure 1) at any given frequency. Richard[10] reported this tendency for six frequencies, and Kulpa attributed the high attenuation to ". . . the large, more irregular shape of the snow precipitation and the fact that higher concentrations exist for the snow due to the low fall velocities."[2] Unfortunately, Oomori gave no details on the physical characteristics of snow. These characteristics determine the "statistical variations and qualities of the snow and precipitation."[8]

Nishitsuji[7] was more conventional than Oomori in his comparison of measured and calculated attenuation at 15, 35, and 50 GHz. Six of the eight pages of his paper were devoted to transforming field snowflake measurements into data on the attenuation cross section and size distribution of snowflakes, which in turn are needed for calculated attenuation. Snow was placed into dry, moist, wet, and watery categories, each with five parameters, including temperature and density. As seen in figure 1, moist, wet, and watery conditions prevailed during the field measurements. Calculated and measured values agreed well according to Nishitsuji, and the trend toward greater attenuation seen in Oomori's work was also present. A comparison of the 15 and 35 GHz curves reveals that water content also contributes to greater attenuation.

---

[8]T. Oomori and S. Aoyagi, 1971, "A Presumptive Formula for Snowfall Attenuation of Radio Waves," Electronics and Communications in Japan, 54-B:34

[11]E. Asari, 1974, "Attenuation of Microwaves in Moist or Wet Snowfall," Electronics and Communications in Japan, 57-B:58

[10]W. W. Richard, J. E. Kammerer, and R. G. Reitz, 1977, "140-GHz Attenuation and Optical Visibility Measurements of Fog, Rain, and Snow," Memorandum Report, ARBRL-MR-2800, Ballistics Research Laboratories, Aberdeen Proving Ground, MD

[2]S. M. Kulpa and E. A. Brown, 1979, Near-Millimeter Wave Technology Base Study: Volume I - Propagation and Target/Background Characteristics, Special Report, HDL-SR-79-8, Harry Diamond Laboratories, Adelphi, MD

[7]A. Nishitsuji, 1971, "Method of Calculation of Radio-Wave Attenuation in Snowfall," Electronics and Communications in Japan, 54-B:74

The remaining curves in figure 1 represent the data of four groups, each working at single frequencies.[5,6,9,10] Apparently in all cases, the only snow characteristic quantitatively measured was snowfall intensity in equivalent rain rate (millimeters per hour).

Robinson[5] and Malinkin et al[9] worked at 35 GHz. The former reported 2.5 times greater attenuation in wet snow than attenuation caused by rain at the same precipitation rate. On the other hand, Malinkin experienced 2.5 times less attenuation for dry snow. Rain data from Richard et al,[10] also reproduced in Kulpa and Brown,[2] are plotted as dots in figure 1 for selected frequencies. These data averaged from several sources by Richard correspond within one order of magnitude at a snowfall intensity of 1 mm/h. Robinson and Malinkin also agree with Nishitsuji[7] and Lammers[12] at 35 GHz for wet and dry snow, respectively.

Richard et al[10] and Babkin[6] experienced the highest attenuations according to figure 1. These attenuation rates would be expected from the foregoing discussion. Richard's measurements of 140 GHz attenuation made through large, moist snowflakes reached a maximum of 5.5 dB/km at the snowfall rate of 1.2 mm/h. Generally, attenuation was three times greater than for rain at the same equivalent rain rate, and three to five times greater than for five other cited investigations in millimeter-wave propagation. Babkin did not qualitatively describe snow during his 312 GHz experiment. However, dry conditions are implied since dry, not wet, snow is theoretically discussed; and maximum

---

[5]N. P. Robinson, 1955, "Measurements of the Effect of Rain, Snow, and Fogs on 8.6 mm Radar Echoes," Proceedings IEEE, London, 203B:709

[6]Yu. S. Babkin et al, 1970, "Attenuation of Radiation at a Wavelength of 0.96 mm in Snow," Radio Engineering and Electronic Physics, 15:2171

[9]V. G. Malinkin, A. V. Sokolov, and Ye. V. Sukhonin, 1976, "Attenuation of Signal at the Wavelength λ = 8.6 mm in Hydrometeors," Radio Engineering and Electronic Physics, 21:1

[10]W. W. Richard, J. E. Kammerer, and R. G. Reitz, 1977, "140-GHz Attenuation and Optical Visibility Measurements of Fog, Rain, and Snow," Memorandum Report, ARBRL-MR-2800, Ballistics Research Laboratories, Aberdeen Proving Ground, MD

[2]S. M. Kulpa and E. A. Brown, 1979, Near-Millimeter Wave Technology Base Study: Volume I - Propagation and Target/Background Characteristics, Special Report, HDL-SR-79-8, Harry Diamond Laboratories, Adelphi, MD

[7]A. Nishitsuji, 1971, "Method of Calculation of Radio-Wave Attenuation in Snowfall," Electronics and Communications in Japan, 54-B:74

[12]U. Lammers, 1967, "The Attenuation of mm-Waves by Meteorological Precipitation," NTZ Communications Journal, 6:230

attenuations were only 30 to 40 percent greater than for previously reported rain measurements. Dry snow would explain the fact that his attenuation curve is only slightly higher than Richard's curve for wet snow at 140 GHz.

Single values for snow and sleet (partly frozen rain) are sometimes encountered in the literature, often in conjunction with rain experiments. Some examples of these values at millimeter wavelengths are:

a. Weibel[13] - 4 dB additional fade at 90 GHz during heavy, wet snowfall.

b. Tattersall[14] - 34 dB fade at 37 GHz for 11, 22, and 37 GHz during severe, wet storm.

c. Misme[15] - 15 to 25 dB loss for several minutes on vertically and horizontally polarized channels at 11 GHz during severe sleeting.

d. Watson[16] - 2 dB/km co-polar and cross-polar fades at 11 GHz during rain, sleet, and snow conditions.

Watson also wrote a review on the lower millimeter wavelengths[17] in which he reported briefly on snow and sleet, citing several papers in this area of research.

A summary of measured attenuation shows that snow, notably in its melting state, is the only nonliquid hydrometeor with any substantial amount of reported data. Open literature tends to show that snow attenuation increases with frequency, snowfall rate, and snowflake liquid water content.

---

[13]G. E. Weibel and H. O. Dressel, 1967, "Propagation Studies in Millimeter-Wave Link Systems," Proceedings IEEE, 55:497

[14]R. L. O. Tattersall, 1975, "Snow Fading on 1 March 1974 on Microwave Links in the Mendlesham Propagation Experiment," Electronics Letters, 11:603

[15]P. Misme, 1979, "Un Affaiblissement Exceptionnel dû a la Neige Mouillee," (An Exceptional Attenuation due to Sleet), Annales des Telecommunication, 34:291

[16]P. A. Watson, 1973, "Attenuation and Cross-Polarization Measurements at 11 GHz," IEEE Transactions Communications, COM-21:325

[17]P. A. Watson, 1976, "Survey of Measurements of Attenuation by Rain and Other Hydrometeors," Proceedings IEEE, London, 123:863

THEORETICAL CALCULATION AND MEASURED BACKSCATTER

Theoretical calculations incorporating hydrometeor field data are necessary for interpreting experimental field measurements. From Ryde and Ryde in 1945[9] to Evans and Holt in 1980,[18] solid and melting precipitation have been considered along with rain. But the irregular shape and variable index of refraction of these particles make comparisons between measured and calculated values difficult. There are no generally accepted field data for these particles such as the Laws-Parson and Marshall-Palmer raindrop size distributions.[19, 20] For convenience, this section of the report is separated into discussions of hail and snow. Hail and sleet are often modeled as spheroids with an ice or ice and water dielectric constant. Snow modeling is a more difficult task, with dry snow conditions producing the best agreement between theory and experiment.

Hail

In view of the lack of experimental data on radio propagation through hail,[2] the validity of representing hailstones as concentric spheres or prolate

---

[9]J. W. Ryde and D. Ryde, 1945, Attenuation of Centimetre and Millimetre Waves by Rain, Hail, Fogs and Clouds, Report 8670, General Electric Research Laboratories, Wembley, England

[18]B. G. Evans and A. R. Holt, 1980, "A Review of Theoretical Prediction Techniques of Transmission Parameters for Slant-Path, Earth-Space Communications," AGARD Conference Proceedings, AGARD-CP-284:3-1, London, UK, 12-16 May 1980

[19]J. O. Laws and D. A. Parsons, 1943, "The Relation of Raindrop-Size to Intensity," Transactions, American Geophysical Union, 24:452

[20]J. S. Marshall and W. McK. Palmer, 1948, "The Distribution of Raindrops with Size," Journal of Meteorology, 5:165

[2]S. M. Kulpa and E. A. Brown, 1979, Near-Millimeter Wave Technology Base Study: Volume I - Propagation and Target/Background Characteristics, Special Report, HDL-SR-79-8, Harry Diamond Laboratories, Adelphi, MD

spheroids[21-27] needs to be compared to direct field observations.[28] [29] Barge and Isaac[28] analyzed nearly 2000 Alberta specimens and found that about 70 percent were oblate and prolate ellipsoids and cones. Wide variability in their data was apparent when 74 percent were cones in one storm and 72 percent were oblate spheroids in another storm only 8 days later. Matson and Huggins[29] photographed hailstones in several Colorado storms and classified the majority as oblate spheroids and 16 percent as cones. Variability in maximum dimension and size distribution from event to event was also reported.

Literature contains several examples where questions have been raised regarding single-model backscatter calculations proposed as a way of separating rain from hail. The following recent example illustrates the need for field data on hailstone shape to clarify this long-standing problem. According to Seliga and Bringi,[27] large, dry hail modeled as an oblate spheroid would yield a differential backscatter (that is, the ratio of vertical to horizontal polarization) which is negative, as opposed to a positive value for rain. Aydin and Hizal's calculations with cones as well as oblate spheroids reveal that

---

[21]E. Asari, 1969, "Analysis and Algorith for Computing the Forward Scattering Cross Section of a Dielectric Sphere," Electronics and Communications in Japan, 52-B:43

[22]M. T. Abshayev and V. I. Rozenberg, 1969, "Scatter and Attenuation of Radar Emission by Water-Surrounded Hailstones," Atmospheric and Oceanic Physics, 5:560

[23]V. I. Rozenberg, 1970, "Scattering of Microwaves by Flaky Hailstones," Atmospheric and Oceanic Physics, 6:91

[24]V. I. Rozenberg, 1970, "Diffraction and Scattering of Electromagnetic Waves by an Inhomogeneous Sphere," Izvestiya Vysshikh Uchebnykh Zavendenii, Radiofizika, 13:337

[25]V. I. Rozenberg and R. M. Vorob'yev, 1971, "Scattering and Attenuation of 3.2-cm Microwaves by Inhomogeneous Hail Particles," Atmospheric and Oceanic Physics, 7:632

[26]A. W. Dissanayake and P. A. Watson, 1977, "Forward Scatter and Cross-Polarization from Spheroidal Ice Particles," Electronics Letters, 13:140

[27]. T. A. Seliga and V. N. Bringi, 1978, "Differential Reflectivity and Differential Phase Shift: Applications in Radar Meteorology," Radio Science, 13:271

[28]B. L. Barge and G. A. Isaac, 1973, "The Shape of Alberta Hailstones," Journal de Recherches Atmospheriques, 7:11

[29]R. J. Matson and A. W. Huggins, 1980, "The Direct Measurement of the Sizes, Shapes and Kinematics of Falling Hailstones," Journal of the Atmospheric Sciences, 37:1107

under certain circumstances hail identification may become difficult and other polarization ratios may be needed for clarification.[10]

Hail size distributions obtained by Khorguani and Tlisov[11] and Federer and Waldvogel[12] in mountainous regions of Europe were different from those of earlier workers. Khorguani concluded that a "logarithmically normal" distribution was a better fit than the gamma function and bimodal ones of his Russian colleagues. Federer's data appeared to have an exponential fit as shown in figure 2.

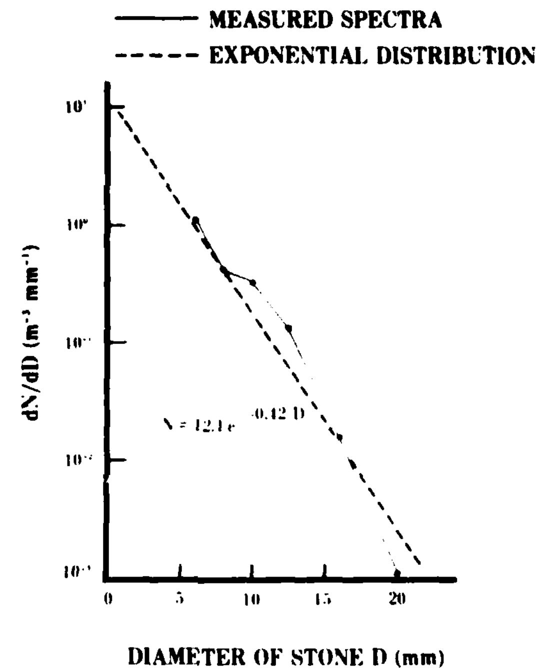


Figure 2. Mean hail distribution from Federer and Waldvogel, 1975, Journal of Applied Meteorology, 14:91. Hailstones defined as particles with $D \geq 5$ mm.

---

[10] K. Aydin and A. Hizal, 1979, "Back-Scattering from Melting Hail-Pellets," IEEE-URSI International Symposium, Antennas and Propagation, p 503, Seattle, WA

[11] V. G. Khorguani and M. I. Tlisov, 1974, "Size Distribution Function of Hailstones," Atmospheric and Oceanic Physics, 10:269

[12] B. Federer and A. Waldvogel, 1975, "Hail and Raindrop Size Distributions from a Swiss Multicell Storm," Journal of Applied Meteorology, 14:91

Snow

Although open literature does not contain experimental data on hail, it does contain experimental data on radio propagation through falling snow (discussed in preceding paragraphs of this report). But the complex shape of snowflakes and their ice-air-water composition make theoretical calculations more difficult than for hail and sleet. Richard et al[10] in a brief review of snow attenuation pointed out that calculations based on equivalent rain rate, particularly for melting snow, are usually lower than measured results. This statement implies that a poor comparison will occur even when a dry snowflake is modeled as a water sphere. This situation appears to be the case in Babkin's comparison with Mie theory calculations based on an "equivalent" water sphere.[6]

Lammers[12] assigned complex dielectric values to snow as an ice-air mixture (a very dry condition) and showed that the total cross section (which includes attenuation and scatter) for Mie calculations at 54 GHz is one order of magnitude smaller than for rain. He also calculated attenuation for dry snow and claimed agreement within one order of magnitude of field measurements. His calculations (figure 3) also appear to agree with other curves of figure 1 to the same order of magnitude

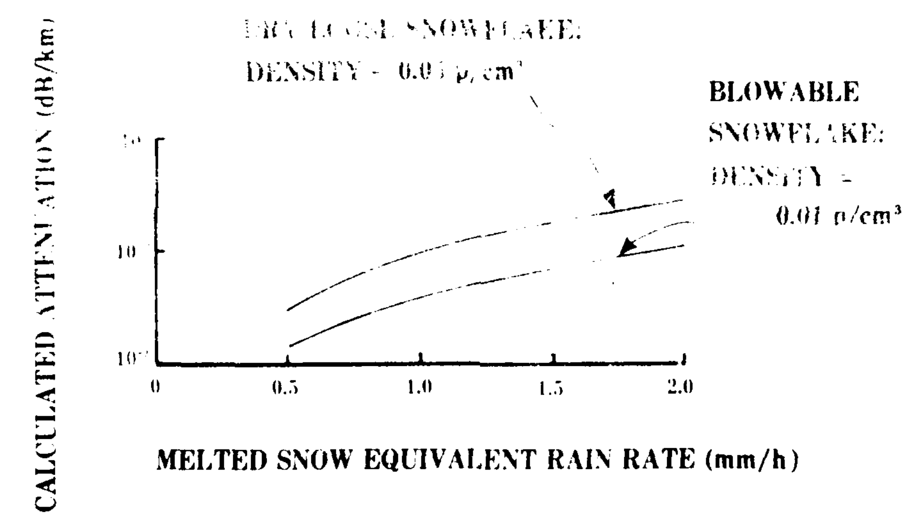


Figure 3. Calculated attenuation at 54 GHz from Lammers, 1967, NTZ Communications Journal, 6:230.

---

[10] W. W. Richard, J. E. Kammerer, and R. G. Reitz, 1977, "140-GHz Attenuation and Optical Visibility Measurements of Fog, Rain and Snow," Memorandum Report, ARBRL-MR-2800, Ballistics Research Laboratories, Aberdeen Proving Ground MD

[6] Yu. S. Babkin et al, 1970, "Attenuation of Radiation at a Wavelength of 0.96 mm in Snow," Radio Engineering and Electronic Physics, 15:2171

[12] U. Lammers, 1967, "The Attenuation of mm-Waves by Meteorological Precipitation," NTZ Communications Journal, 6:230

Size distribution of snowflakes and graupels (granular snow pellets) has been studied mainly by weather radar experimenters because of the importance of identifying and assessing the quantity of hydrometeor particles. The desired parameters are generally the radar reflectivity Z plotted against precipitation intensity or rate R.[3] Since comparison between rain and the snowfall equivalent rain rate is frequently made, the mass of the snowflake rather than its physical size is measured.[13] The technique often employed is to measure the diameter of the drop resulting from melting a snowflake on filter paper coated with a water-soluble dye such as gentian violet.[7, 13, 14, 15] A more elaborate method is to measure photographs of crystals reduced to spheres in heated silicone oil.[16] The terminal velocity of snowflakes, needed to compute the mass-size distribution on a volume basis (millimeter^{-1} m^{-3}), is usually taken from Langleben.[17] Mogono[18] stated that Langleben's fall velocities are applicable to small snowflakes only and that the velocities are related more to size and density than to mass.

Previous attempts to relate backscatter measurements to calculations based on snow size distributions have had mixed success. Imai et al[15] found that snowflake coalescence affected size distribution to such an extent that the Z-R coefficient changed by about a factor of 4 in a 2-h period. Gunn and Marshall[13] reported that their distribution using Langleben's velocities

---

[3] H. K. Kobayashi, 1980, Atmospheric Effects on Millimeter Radio Waves, ASL-TR-0049, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, AD A081414

[13] K. L. S. Gunn and J. S. Marshall, 1958, "The Distribution with Size of Aggregate Snowflakes," Journal of Meteorology, 15:452

[7] A. Nishitsuji, 1971, "Method of Calculation of Radio-Wave Attenuation in Snowfall," Electronics and Communications in Japan, 54-B:74

[14] T. Yagi, H. Uyeda, and H. Seino, 1979, "Size Distribution of Snowflakes and Graupel Particles Observed in Nagaoka, Niigate Perfecture," Journal of the Faculty of Science, Hokkaido University, Ser VII, 6:79

[15] I. Imai et al, 1955, "Radar Reflectivity of Falling Snow," Meteorology and Geophysics (Japan), 6:130

[16] M. Kajikawa, 1972, "Measurement of Falling Velocity of Individual Snow Crystals," Journal of the Meteorological Society of Japan, 50:577

[17] M. P. Langleben, 1954, "The Terminal Velocity of Snowflakes," Quarterly Journal of the Royal Meteorological Society, 80:174

[18] C. Magono, 1965, "Aerodynamic Studies of Falling Snowflakes," Journal of the Meteorological Society of Japan, 43:139

(figure 4) agreed with Imai's data and the Marshall-Palmer rain distribution[28] at low intensities of R (figures 5 and 6). A recent study by Yagi et al[34] compared well with the Gunn and Marshall distribution (figure 7). However, the authors clearly showed that the same reflectivity Z can be returned by two storms differing greatly in size and distribution of snowflake and graupel. On the basis of their findings, Yagi recommended restricting the usage of the Z-R relationship for snow to weather at a specific locale.

In a few papers, the morphology or physical state of snowflakes has been explicitly related to attenuation or scatter. A typical example was by Asari[11] who divided snow into six categories, from slightly moist to very wet, each with a particular dielectric constant at 11, 24, and 35 GHz. He then found the total cross section and compared attenuation with measured data at 11 and 35 GHz. Although no experimental confirmation was apparent, Asari's calculations for attenuation by particles of "equal nature and size" (figure 8) indicate that at 11 and 35 GHz a unique maximum is attained in each of the six snow categories.

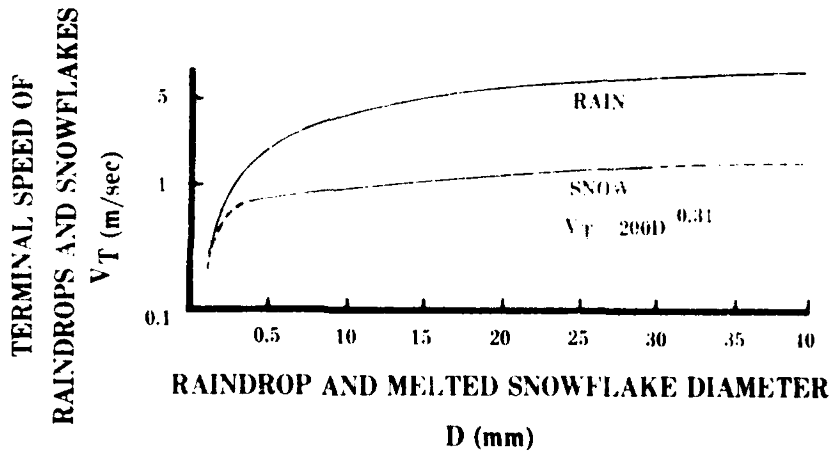


Figure 4. Terminal speeds of raindrops (from Gunn and Kinzer, 1949, Journal of Meteorology, 6:243) and snowflakes (from Langleben, 1954, Quarterly Journal of the Royal Meteorological Society, 80:174) as a function of diameter.

---

[28] J. S. Marshall and W. McK. Palmer, 1948, "The Distribution of Raindrops with Size," Journal of Meteorology, 5:165

[34] T. Yagi, H. Uyeda, and H. Seino, 1979, "Size Distribution of Snowflakes and Graupel Particles Observed in Nagaoka, Niigate Perfecture," Journal of the Faculty of Science, Hokkaido University, Ser VII, 6:79

[11] E. Asari, 1974, "Attenuation of Microwaves in Moist or Wet Snowfall," Electronics and Communications in Japan, 57-B:58

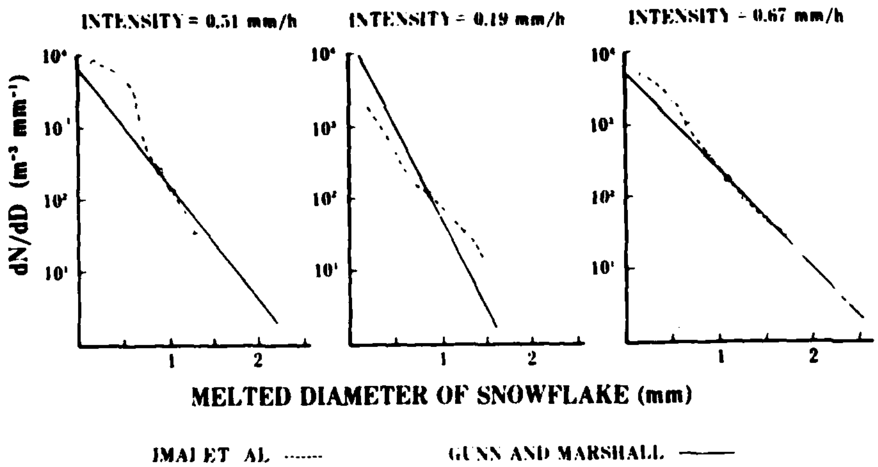


Figure 5. Three average size distributions for snow from Imai et al, Meteorology and Geophysics (Japan), 6:130 (dotted lines) and Gunn and Marshall, 1958, Journal of Meteorology, 15:452 (straight lines).

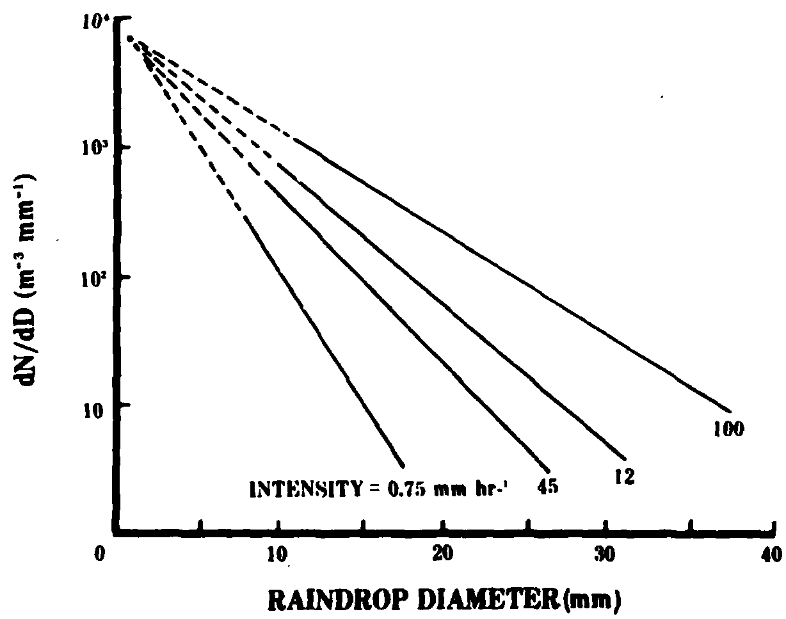


Figure 6. Marshall-Palmer (1948) average rain distributions for four intensities from Journal of Meteorology, 5:165.

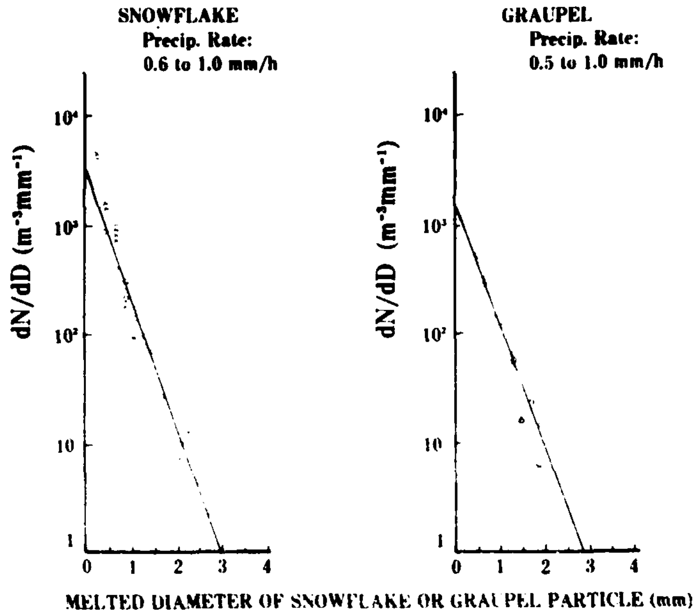


Figure 7. Size distribution for snowflakes and graupel particles from Yagi et al, 1979, Journal of the Faculty of Science, Hokkaido University, Ser VII, 6:79.

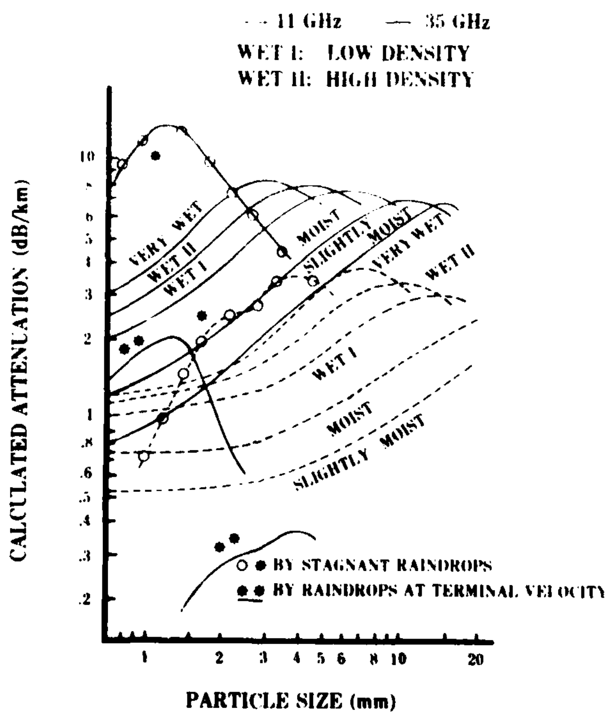


Figure 8. Calculated attenuation by various kinds of snow particles from Asari, Electronics and Communications in Japan, 57-B:58.

A summary of theoretical calculations, especially with respect to backscatter, shows that the effect of hail on millimeter waves is hampered by the lack of field measurements taken in concert with data on the morphology and distribution of hailstones. For snow, good agreement between experiment and theory is found for small, dry flakes represented as an ice and air spheroid. For larger, wetter flakes having the tendency to aggregate with size, no satisfactory model has been found in the literature, and calculated values based on spheroids show poorer correlation with experimental values.

LABORATORY MEASURMENTS OF SINGLE PARTICLES

Attempts to predict attenuation and scatter from hydrometeors at millimeter wavelengths began with Ryde and Ryde* during World War II with solid and liquid particles (rain, hail, and fog). Later, Gunn and Marshall** and Marshall and Gunn** extended Rydes' work to snow ". . .conveniently expressed in terms of the diameter of the water drop to which the snowflake would melt, assuming no break-up." It was soon realized that no one meteorological factor would suffice to link size distribution and synoptic condition. However, as late as 1970, Babkin et al* assumed a spherical shape for snow and applied Gunn and Marshall's size distribution to Mie theory computations. Their results show poor comparison between measured and computed curves. Since Babkin's work at 312 GHz appears to be the only one available for snow at the high millimeter frequencies, his involved argument for introducing an "effective radii of spherical snow particles" should be examined with care. Thus it appears that problems are encountered in assuming simple shapes for hydrometeors, and therefore it would be very useful to obtain direct measurements of attenuation and scatter from particles of known configuration.

The need to collect data on the effect of hydrometeor particles under controlled laboratory conditions has resulted in a small body of papers from about

---

*J. W. Ryde and D. Ryde, 1945, Attenuation of Centimetre and Millimetre Waves by Rain, Hail, Fogs, and Clouds, Report 8670, General Electric Research Laboratories, Wembley, England

**K. L. S. Gunn and J. S. Marshall, 1958, "The Distribution with Size of Aggregate Snowflakes," Journal of Meteorology, 15:452

**J. S. Marshall and K. L. S. Gunn, 1952, "Measurement of Snow Parameters by Radar," Journal of Meteorology, 9:322

*Yu. S. Babkin et al, 1970, "Attenuation of Radiation at a Wavelength of 0.96 mm in Snow," Radio Engineering and Electronic Physics, 15:2171

1952 to 1980.[40-47] All of these papers are measurements of single particles, the multiple-scattering interactions being intractable in experimentation as well as theory. They fall into two kinds of determinations:

a. Backscatter matrix based on various techniques,[41-44] and

b. Extinction cross section (attenuation plus scatter) based on a technique by Cullen and Kumar.[45, 46, 47]

Backscatter measurements were made by Labrum[40] in 1952 at 3 GHz on liquid spheres and melting rods and discs of approximately 0.1 wavelength. He confirmed the "bright band" backscatter phenomenon and polarization rotation from nonspherical scatterers long observed by radar operators. Nicholis[42] examined the 18 to 25 GHz range with rectangular frozen specimens of resonant wavelength and agreed with Labrum in detecting a backscatter maximum during melting at the lower wavelengths. In his comprehensive theoretical paper on scattering and absorption by hail modeled as melting ice spheres at 34.8 GHz, Oguchi[48] also found a maximum during the melting process.

---

[40]N. R. Labrum, 1952, "Some Experiments on Centimeter-Wavelength Scattering by Small Obstacles," Journal of Applied Physics, 23:1320

[41]N. R. Labrum, 1952, "The Scattering of Radio Waves by Meteorological Particles," Journal of Applied Physics, 23:1324

[42]J. Nicholis, 1965, "The Wavelength Dependence (between 18 to 25 Gc/s) of Back-Reflected Energy from Small Ice Particles during the Melting Process," Proceedings of the IEEE, 53:551

[43]L. E. Allan and G. C. McCormick, 1978, "Measurements of the Backscatter Matrix of Dielectric Spheroids," IEEE Transactions on Antennas and Propagation, AP-26:579

[44]L. E. Allan and G. C. McCormick, 1980, "Measurements of the Backscatter Matrix of Dielectric Bodies," IEEE Transactions on Antennas and Propagation, AP-28:166

[45]A. L. Cullen and A. Kumar, 1970, "The Absolute Determination of Extinction Cross-Sections by the Use of an Open Resonator," Proceedings of the Royal Society of London, Sect A, 315:217

[46]J. R. Gerhardt et al, 1961, "Experimental Determinations of the Backscattering Cross-Section of Water Drops and of Wet and Dry Ice Spheres at 3.2 Centimeters," Journal of Meteorology, 18:340

[47]D. L. Bryant and L. J. Auchterlonie, 1978, "Measurement of the Extinction Cross-Sections of Dry and Wet Ice Spheres at 35 GHz," Electronics Letters, 15:52

[48]T. Oguchi, 1966, "Scattering and Absorption of a Millimeter Wave Due to Rain and Melting Hailstones," Journal of the Radio Research Laboratories (Japan), 13:141

Recently, Allan and McCormick,[43] [44] with measurements at 2.86 GHz, related scattering coefficients in the horizontal and vertical planes to the aspect angle (that is, the angle between the symmetry axis and the propagation direction) for dielectric spheroids 0.242 to 1.22 wavelengths maximum dimension simulating ice (dielectric constant $\epsilon = 3.18$). Some agreement with theory and measurement by others is claimed by the authors, although conspicuous differences were seen in the backscatter cross section for spheroids in the Rayleigh region.

Extinction cross section by Cullen and Kumar's method[45] involves a simple, straightforward measurement of the change in Q-factor due to an obstacle placed in an open resonator. The obstacle must have reflective symmetry perpendicular to the incident wave, and thus far only spheroids have been studied with this method. Experiments by Gerhardt et al[46] at 9.4 GHz with water drops and wet and dry ice spheres 0.5- to 11.0-wavelength diameter were *in general agreement* with Mie theory except for the melting values. Bryant and Auchterlonie[47] also encountered difficulty in preparing specimens and interpreting results with ice spheres. Their problem was in qualitatively assessing the degree of melt when replicating their readings at the wavelength of only 8.6 mm (35 GHz).

A summary of laboratory measurements of single particles shows that mixed results have been reported for ice, melting ice, and synthetic dielectric particles of spherical to rectangular shapes of resonant size between 2.86 and 35 GHz. A serious technical problem is assessing the degree of melt for ice-water specimens in replicating data. This problem will become acute at higher millimeter frequencies with their smaller resonant particles.

---

[43] L. E. Allan and G. C. McCormick, 1978, "Measurements of the Backscatter Matrix of Dielectric Spheroids," <u>IEEE Transactions on Antennas and Propagation</u>, AP-26:579

[44] L. E. Allan and G. C. McCormick, 1980, "Measurements of the Backscatter Matrix of Dielectric Bodies," <u>IEEE Transactions on Antennas and Propagation</u>, AP-28:166

[45] A. L. Cullen and A. Kumar, 1970, "The Absolute Determination of Extinction Cross-Sections by the Use of an Open Resonator," <u>Proceedings of the Royal Society of London</u>, Sect A, 315:217

[46] J. R. Gerhardt et al, 1961, "Experimental Determinations of the Backscattering Cross-Section of Water Drops and of Wet and Dry Ice Spheres at 3.2 Centimeters," <u>Journal of Meteorology</u>, 18:340

[47] D. L. Bryant and L. J. Auchterlonie, 1978, "Measurement of the Extinction Cross-Sections of Dry and Wet Ice Spheres at 35 GHz," <u>Electronics Letters</u>, 15:52

CONCLUSIONS

Snow, notably in its melting state, is the only nonliquid hydrometeor with any substantial amount of reported data at millimeter wavelengths. The open literature tends to show that snow attenuation increases with frequency, equivalent rain rate, and snowflake liquid water content.

Hail and sleet are more amenable to theoretical calculation and laboratory experimentation than snow because of their simpler approximations of particle shape and dielectric constant. On the other hand, field measurements on hail and sleet are comparatively scarce due to their transient nature.

Apparently the lack of reliable field data on hydrometeors other than rain has made comparison between experimental measurement and theoretical calculation difficult.

RECOMMENDATIONS

The most pressing need is for field data on characteristics of hydrometeor particles taken with the usual equivalent rain rate. Several references in this review have pointed out what characteristics are important for theoretical calculations. As with rain,[19] [20] [49] data for other hydrometeors are

---

[19] J. O. Laws and D. A. Parsons, 1943, "The Relation of Raindrop-Size to Intensity," Transactions, American Geophysical Union, 24:452

[20] J. S. Marshall and W. McK. Palmer, 1948, "The Distribution of Raindrops with Size," Journal of Meteorology, 5:165

[49] R. Gunn and G. D. Kinzer, 1949, "The Terminal Velocity of Fall for Water Droplets in Stagnant Air," Journal of Meteorology, 6:243

still valuable even if not taken in conjunction with radio propagation measurements.[28, 29, 31, 32, 33, 34, 36, 37]

Melting snow has been shown to affect millimeter waves to the same extent as rain and should be given priority over less effective hydrometeors of lower liquid water content. Comparative treatment of melting snow and rain during the same storm[50, 51] is especially valuable because the effect of rain is relatively well understood up to 140 GHz.[52]

---

[28]B. L. Barge and G. A. Isaac, 1973, "The Shape of Alberta Hailstones," *Journal de Recherches Atmosphériques*, 7:11

[29]R. J. Matson and A. W. Huggins, 1980, "The Direct Measurement of the Sizes, Shapes and Kinematics of Falling Hailstones," *Journal of the Atmospheric Sciences*, 37:1107

[31]V. G. Khorguani and M. I. Tlisov, 1974, "Size Distribution Function of Hailstones," *Atmospheric and Oceanic Physics*, 10:269

[32]B. Federer and A. Waldvogel, 1975, "Hail and Raindrop Size Distributions from a Swiss Multicell Storm," *Journal of Applied Meteorology*, 14:91

[33]K. L. S. Gunn and J. S. Marshall, 1958, "The Distribution with Size of Aggregate Snowflakes," *Journal of Meteorology*, 15:452

[34]T. Yagi, H. Uyeda, and H. Seino, 1979, "Size Distribution of Snowflakes and Graupel Particles Observed in Nagaoka, Niigata Perfecture," *Journal of the Faculty of Science*, Hokkaido University,Ser VII, 6:79

[36]M. Kajikawa, 1972, "Measurement of Falling Velocity of Individual Snow Crystals," *Journal of the Meteorological Society of Japan*, 50:577

[37]M. P. Langleben, 1954, "The Terminal Velocity of Snowflakes," *Quarterly Journal of the Royal Meteorological Society*, 80:174

[50]T. Ohtake, 1969, "Observations of Size Distributions of Hydrometeors Through the Melting Layer," *Journal of the Atmospheric Sciences*, 36:546

[51]T. Ohtake, 1970, "Factors Affecting the Size Distribution of Raindrops and Snowflakes," *Journal of the Atmospheric Sciences*, 27:804

[52]S. Okamura and A. Sonohara, 1977, "Atmospheric Attenuation by Rain at 140 GHz," *Electronics and Communications in Japan*, 60-B:94

REFERENCES

1. Brown, D. M., and M. B. Wells, 1978, A Literature Review of Millimeter and Submillimeter Radiation Absorption and Scatter in the Atmosphere, Final Report, ARBRL-CR-00382, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, AD A062375.

2. Kulpa, S. M., and E. A. Brown, 1979, Near-Millimeter Wave Technology Base Study: Volume I - Propagation and Target/Background Characteristics, Special Report, HDL-SR-79-8, Harry Diamond Laboratories, Adelphi, MD.

3. Kobayashi, H. K., 1980, Atmospheric Effects on Millimeter Radio Waves, ASL-TR-0049, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, AD A081414.

4. Ryde, J. W., and D. Ryde, 1945, Attenuation of Centimetre and Millimetre Waves by Rain, Hail, Fogs and Clouds, Report 8670, General Electric Research Laboratories, Wembley, England.

5. Robinson, N. P., 1955, "Measurements of the Effect of Rain, Snow and Fogs on 8.6 mm Radar Echoes," Proceedings IEEE, London, 203B:709.

6. Babkin, Yu. S., et al, 1970, "Attenuation of Radiation at a Wavelength of 0.96 mm in Snow," Radio Engineering and Electronic Physics, 15:2171.

7. Nishitsuji, A., 1971, "Method of Calculation of Radio-Wave Attenuation in Snowfall," Electronics and Communications in Japan, 54-B:74.

8. Oomori, T., and S. Aoyagi, 1971, "A Presumptive Formula for Snowfall Attenuation of Radio Waves," Electronics and Communications in Japan, 54-B:34.

9. Malinkin, V. G., A. V. Sokolov, and Ye. V. Sukhonin, 1976, "Attenuation of Signal at the Wavelength λ = 8.6 mm in Hydrometeors," Radio Engineering and Electronic Physics, 21:1.

10. Richard, W. W., J. E. Kammerer, and R. G. Reitz, 1977, "140-GHz Attenuation and Optical Visibility Measurements of Fog, Rain and Snow," Memorandum Report, ARBRL-MR-2800, Ballistics Research Laboratories, Aberdeen Proving Ground, MD.

11. Asari, E., 1974, "Attenuation of Microwaves in Moist or Wet Snowfall," Electronics and Communications in Japan, 57-B:58.

12. Lammers, U., 1967, "The Attenuation of mm-Waves by Meteorological Precipitation," NTZ Communications Journal, 6:230.

13. Weibel, G. E., and H. O. Dressel, 1967, "Propagation Studies in Millimeter-Wave Link Systems," Proceedings IEEE, 55:497.

14. Tattersall, R. L. O., 1975, "Snow Fading on 1 March 1974 on Microwave Links in the Mendlesham Propagation Experiment," Electronics Letters, 11:603.

15. Misme, P., 1979, "Un Affaiblissement Exceptionnel dû a la Neige Mouillee" (An Exceptional Attenuation due to Sleet), Annales des Telecommunication, 34:291.

16. Watson, P. A., 1973, "Attenuation and Cross-Polarization Measurements at 11 GHz," IEEE Transactions Communications, COM-21:325.

17. Watson, P. A., 1976, "Survey of Measurements of Attenuation by Rain and Other Hydrometeors," Proceedings IEEE, London, 123:863.

18. Evans, B. G., and A. R. Holt, 1980, "A Review of Theoretical Prediction Techniques of Transmission Parameters for Slant-Path, Earth-Space Communications," AGARD Conference Proceedings, AGARD-CP-284:3-1, London, UK, 12-16 May 1980.

19. Laws, J. O., and D. A. Parsons, 1943, "The Relation of Raindrop-Size to Intensity," Transactions, American Geophysical Union, 24:452.

20. Marshall, J. S., and W. McK. Palmer, 1948, "The Distribution of Raindrops with Size," Journal of Meteorology, 5:165.

21. Asari, E., 1969, "Analysis and Algorith for Computing the Forward Scattering Cross Section of a Dielectric Sphere," Electronics and Communications in Japan, 52-B:43.

22. Abshayev, M. T., and V. I. Rozenberg, 1969, "Scatter and Attenuation of Radar Emission by Water-Surrounded Hailstones," Atmospheric and Oceanic Physics, 5:560.

23. Rozenberg, V. I., 1970, "Scattering of Microwaves by Flaky Hailstones," Atmospheric and Oceanic Physics, 6:91.

24. Rozenberg, V. I., 1970, "Diffraction and Scattering of Electromagnetic Waves by an Inhomogeneous Sphere," Izvestiya Vysshikh Uchebnykh Zavendenii, Radiofizika, 13:337.

25. Rozenberg, V. I., and R. M. Vorob'yev, 1971, "Scattering and Attenuation of 3.2-cm Microwaves by Inhomogeneous Hail Particles," Atmospheric and Oceanic Physics, 7:632.

26. Dissanayake, A. W., and P. A. Watson, 1977, "Forward Scatter and Cross-Polarization from Spheroidal Ice Particles," Electronics Letters, 13:140.

27. Seliga, T. A., and V. N. Bringi, 1978, "Differential Reflectivity and Differential Phase Shift: Applications in Radar Meteorology," Radio Science, 13:271.

28. Barge, B. L., and G. A. Isaac, 1973, "The Shape of Alberta Hailstones," Journal de Recherches Atmospheriques, 7:11.

29. Matson, R. J., and A. W. Huggins, 1980, "The Direct Measurement of the Sizes, Shapes and Kinematics of Failing Hailstones," Journal of the Atmospheric Sciences, 37:1107.

30. Aydin, K., and A. Hizal, 1979, "Back-Scattering from Melting Hail-Pellets," IEEE-URSI International Symposium, Antennas and Propagation, Seattle, WA.

31. Khorguani, V. G., and M. I. Tlisov, 1974 "Size Distribution Function of Hailstones," Atmospheric and Oceanic Physics, 10:269.

32. Federer, B., and A. Waldvogel, 1975, "Hail and Raindrop Size Distributions from a Swiss Multicell Storm," Journal of Applied Meteorology, 14:91.

33. Gunn, K. L. S., and J. S. Marshall, 1958, "The Distribution with Size of Aggregate Snowflakes," Journal of Meteorology, 15:452.

34. Yagi, T., H. Uyeda, and H. Seino, 1979, "Size Distribution of Snowflakes and Graupel Particles Observed in Nagaoka, Niigate Perfecture," Journal of the Faculty of Science, Hokkaido University, Ser VII, 6:79.

35. Imai, I., et al, 1955, "Radar Reflectivity of Falling Snow," Meteorology and Geophysics (Japan), 6:130.

36. Kajikawa, M., 1972, "Measurement of Falling Velocity of Individual Snow Crystals," Journal of the Meteorological Society of Japan, 50:577.

37. Langleben, M. P., 1954, "The Terminal Velocity of Snowflakes," Quarterly Journal of the Royal Meteorological Society, 80:174.

38. Magono, C., 1965, "Aerodynamic Studies of Falling Snowflakes," Journal of the Meteorological Society of Japan, 43:139.

39. Marshall, J. S., and K. L. S. Gunn, 1952, "Measurement of Snow Parameters by Radar," Journal of Meteorology, 9:322.

40. Labrum, N. R., 1952, "Some Experiments on Centimeter-Wavelength Scattering by Small Obstacles," Journal of Applied Physics, 23:1320.

41 Labrum, N. R., 1952, "The Scattering of Radio Waves by Meteorological Particles," Journal of Applied Physics, 23:1324.

42. Nicholis, J., 1965, "The Wavelength Dependence (between 18 to 25 Gc/s) of Back-Reflected Energy from Small Ice Particles during the Melting Process," Proceedings of the IEEE, 53:551.

43. Allan, L. E., and G. C. McCormick, 1978, "Measurements of the Backscatter Matrix of Dielectric Spheroids," IEEE Transactions on Antennas and Propagation, AP-26:579.

44. Allan, L. E., and G. C. McCormick, 1980, "Measurements of the Backscatter Matrix of Dielectric Bodies," IEEE Transactions on Antennas and Propagation, AP-28:166.

45. Cullen, A. L., and A. Kumar, 1970, "The Absolute Determination of Extinction Cross-Sections by the Use of an Open Resonator," Proceedings of the Royal Society of London, Sect A, 315:217.

46. Gerhardt, J. R., et al, 1961, "Experimental Determinations of the Back-Scattering Cross-Section of Water Drops and of Wet and Dry Ice Spheres at 3.2 Centimeters," Journal of Meteorology, 18:340.

47. Bryant, D. L., and L. J. Auchterlonie, 1978, "Measurement of the Extinction Cross-Sections of Dry and Wet Ice Spheres at 35 GHz," Electronics Letters, 15:52.

48. Oguchi, T., 1966, "Scattering and Absorption of a Millimeter Wave Due to Rain and Melting Hailstones," Journal of the Radio Research Laboratories (Japan), 13:141.

49. Gunn, R., and G. D. Kinzer, 1949, "The Terminal Velocity of Fall for Water Droplets in Stagnant Air," Journal of Meteorology, 6:243.

50. Ohtake, T., 1969, "Observations of Size Distributions of Hydrometeors Through the Melting Layer," Journal of the Atmospheric Sciences, 36:546.

51. Ohtake, T., 1970, "Factors Affecting the Size Distribution of Raindrops and Snowflakes," Journal of the Atmospheric Sciences, 27:804.

52. Okamura, S., and A. Sonohara, 1977, "Atmospheric Attenuation by Rain at 140 GHz," Electronics and Communications in Japan, 60-B:94.

ELECTRO-OPTICS DISTRIBUTION LIST

Commander
US Army Aviation School
Fort Rucker, AL 36362

Commander
US Army Aviation Center
ATTN: ATZQ-D-MA (Mr. Oliver N. Heath)
Fort Rucker, AL 36362

Commander
US Army Aviation Center
ATTN: ATZQ-D-MS (Mr. Donald Wagner)
Fort Rucker, AL 36362

NASA/Marshall Space Flight Center
ATTN: ES-83 (Otha H. Vaughan, Jr.)
Huntsville, AL 35812

NASA/Marshall Space Flight Center
Atmospheric Sciences Division
ATTN: Code ES-81 (Dr. William W. Vaughan)
Huntsville, AL 35812

Nichols Research Corporation
ATTN: Dr. Lary W. Pinkley
4[illegible]0 South Memorial Parkway
Huntsville, AL 35802

John M. Hobbie
c/o Kentron International
2003 Byrd Spring Road
Huntsville, AL 35802

Mr. Ray Baker
Lockheed-Missile & Space Company
4800 Bradford Blvd
Huntsville, AL 35807

Commander
US Army Missile Command
ATTN: DRSMI-OG (Mr. Donald R. Peterson)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-OGA (Dr. Bruce W. Fowler)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REL (Dr. George Emmons)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REO (Huey F. Anderson)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REO (Mr. Maxwell W. Harper)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REO (Mr. Gene Widenhofer)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RHC (Dr. Julius Q. Lilly)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
Redstone Scientific Information Center
ATTN: DRSMI-RPRD (Documents Section)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RRA (Dr. Oskar Essenwanger)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RRO (Mr. Charles Christensen)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RRO (Dr. George A. Tanton)
Redstone Arsenal, AL 35809

Commander
US Army Communications Command
ATTN: CC-OPS-PP
Fort Huachuca, AZ 85613

Commander
US Army Intelligence Center & School
ATTN: ATSI-CD-CS (Mr. Richard G. Cundy)
Fort Huachuca, AZ 85613

Commander
US Army Intelligence Center & School
ATTN: ATSI-CD-MD (Mr. Harry Wilder)
Fort Huachuca, AZ 85613

Commander
US Army Intelligence Center & School
ATTN: ATSI-CS-C (2LT Coffman)
Fort Huachuca, AZ 85613

Commander
US Army Yuma Proving Ground
ATTN: STEYP-MSA-TL
Bldg 2105
Yuma, AZ 85364

Northrop Corporation
Electro-Mechanical Division
ATTN: Dr. Richard D. Tooley
500 East Orangethorpe Avenue
Anaheim, CA 92801

Commander
Naval Weapons Center
ATTN: Code 3918 (Dr. Alexis Shlanta)
China Lake, CA 93555

Hughes Helicopters
Army Advanced Attack Helicopter Weapons
ATTN: Mr. Charles R. Hill
Centinela and Teale Streets
Bldg 305, MS T-73A
Culter City, CA 90230

Commander
US Army Combat Developments
Experimentation Command
ATTN: ATEC-PL-M (Mr. Gary G. Love)
Fort Ord, CA 93941

SRI International
ATTN: K2060/Dr. Edward E. Uthe
333 Ravenswood Avenue
Menlo Park, CA 94025

SRI International
ATTN: Mr. J. E. Van der Laan
333 Ravenswood Avenue
Menlo Park, CA 94025

Joane May
Naval Environmental Prediction
Research Facility (NEPRF)
ATTN: Library
Monterey, CA 93940

Sylvania Systems Group,
Western Division
GTE Products Corporation
ATTN: Technical Reports Library
P.O. Box 205
Mountain View, CA 94042

Sylvania Systems Group
Western Division
GTE Products Corporation
ATTN: Mr. Lee W. Carrier
P.O. Box 188
Mountain View, CA 94042

Pacific Missile Test Center
Geophysics Division
ATTN: Code 3250-3 (R. de Violini)
Point Mugu, CA 93042

Pacific Missile Test Center
Geophysics Division
ATTN: Code 3253 (Terry E. Battalino)
Point Mugu, CA 93042

Effects Technology Inc.
ATTN: Mr. John D. Carlyle
5383 Hollister Avenue
Santa Barbara, CA 93111

Commander
Naval Ocean Systems Center
ATTN: Code 532 (Dr. Juergen Richter)
San Diego, CA 92152

Commander
Naval Ocean Systems Center
ATTN: Code 5322 (Mr. Herbert G. Hughes)
San Diego, CA 92152

Commander
Naval Ocean Systems Center
ATTN: Code 4473 (Tech Library)
San Diego, CA 92152

The RAND Corporation
ATTN: Ralph Huschke
1700 Main Street
Santa Monica, CA 90406

Particle Measuring Systems, Inc.
ATTN: Dr. Robert G. Knollenberg
1855 South 57th Court
Boulder, CO 80301

US Department of Commerce
National Oceanic and Atmospheric Admin
Environmental Research Laboratories
ATTN: Library, R-51, Technical Reports
325 Broadway
Boulder, CO 80303

US Department of Commerce
National Oceanic and Atmospheric Admin
Environmental Research Laboratories
ATTN: R45X3 (Dr. Vernon E. Derr)
Boulder, CO 80303

US Department of Commerce
National Telecommunications and
Information Administration
Institute for Telecommunication Sciences
ATTN: Code 1-3426 (Dr. Hans J. Liebe)
Boulder, CO 80303

AFATL/DLODL
Technical Library
Eglin AFB, FL 32542

Commanding Officer
Naval Training Equipment Center
ATTN: Technical Information Center
Orlando, FL 32813

Georgia Institute of Technology
Engineering Experiment Station
ATTN: Dr. Robert W. McMillan
Atlanta, GA 30332

Georgia Institute of Technology
Engineering Experiment Station
ATTN: Dr. James C. Wiltse
Atlanta, GA 30332

Commandant
US Army Infantry Center
ATTN: ATSH-CD-MS-E (Mr. Robert McKenna)
Fort Benning, GA 31805

Commander
US Army Signal Center & Fort Gordon
ATTN: ATZHCD-CS
Fort Gordon, GA 30905

Commander
US Army Signal Center & Fort Gordon
ATTN: ATZHCD-O
Fort Gordon, GA 30905

USAFETAC/DNE
ATTN: Mr. Charles Glauber
Scott AFB, IL 62225

Commander
Air Weather Service
ATTN: AWS/DNDP (LTC Kit G. Cottrell)
Scott AFB, IL 62225

Commander
Air Weather Service
ATTN: AWS/DOOF (MAJ Robert Wright)
Scott AFB, IL 62225

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-CAA-Q (Mr. H. Kent Pickett)
Fort Leavenworth, KS 66027

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-SAN (Robert DeKinder, Jr.)
Fort Leavenworth, KS 66027

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-SAN (Mr. Kent I. Johnson)
Fort Leavenworth, KS 66027

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-WE (LTC Darrell Holland)
Fort Leavenworth, KS 66027

President
USAARENBD
ATTN: ATZK-AE-TA (Dr. Charles R. Leake)
Fort Knox, KY 40121

Commander
US Army Armor Center and Fort Knox
ATTN: ATZK-CD-MS
Fort Knox, KY 40121

Commander
US Army Armor Center and Fort Knox
ATTN: ATZK-CD-SD
Fort Knox, KY 40121

Aerodyne Research Inc.
ATTN: Dr. John F. Ebersole
Crosby Drive
Bedford, MA 01730

Commander
Air Force Geophysics Laboratory
ATTN: OPA (Dr. Robert W. Fenn)
Hanscom AFB, MA 01731

Commander
Air Force Geophysics Laboratory
ATTN: OPI (Dr. Robert A. McClatchey)
Hanscom AFB, MA 01731

Massachusetts Institute of Technology
Lincoln Laboratory
ATTN: Dr. T. J. Goblick, B-370
P.O. Box 73
Lexington, MA 02173

Massachusetts Institute of Technology
Lincoln Laboratory
ATTN: Dr. Michael Gruber
P.O. Box 73
Lexington, MA 02173

Raytheon Company
Equipment Division
ATTN: Dr. Charles M. Sonnenschein
430 Boston Post Road
Wayland, MA 01778

Commander
US Army Ballistic Research Laboratory/
ARRADCOM
ATTN: DRDAR-BLB (Mr. Richard McGee)
Aberdeen Proving Ground, MD 21005

Commander/Director
Chemical Systems Laboratory
US Army Armament Research
& Development Command
ATTN: DRDAR-CLB-PS (Dr. Edward Stuebing)
Aberdeen Proving Ground, MD 21010

Commander/Director
Chemical Systems Laboratory
US Army Armament Research
& Development Command
ATTN: DRDAR-CLB-PS (Mr. Joseph Vervier)
Aberdeen Proving Ground, MD 21010

Commander/Director
Chemical Systems Laboratory
US Army Armament Research
& Development Command
ATTN: DRDAR-CLY-A (Mr. Ronnald Pennsyle)
Aberdeen Proving Ground, MD 21010

Commander
US Army Ballistic Research Laboratory/
ARRADCOM
ATTN: DRDAR-TSB-S (STINFO)
Aberdeen Proving Ground, MD 21005

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-CCM (W. H. Pepper)
Adelphi, MD 20783

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-CG/DRDEL-DC/DRDEL-CS
2800 Powder Mill Road
Adelphi, MD 20783

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-CT
2800 Powder Mill Road
Adelphi, MD 20783

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-PAO (M. Singleton)
2800 Powder Mill Road
Adelphi, MD 20783

Project Manager
Smoke/Obscurants
ATTN: DRDPM-SMK
(Dr. Anthony Van de Wal, Jr.)
Aberdeen Proving Ground, MD 21005

Project Manager
Smoke/Obscurants
ATTN: DRDPM-SMK-T (Mr. Sidney Gerard)
Aberdeen Proving Ground, MD 21005

Commander
US Army Test & Evaluation Command
ATTN: DRSTE-AD-M (Mr. Warren M. Baity)
Aberdeen Proving Ground, MD 21005

Commander
US Army Test & Evaluation Command
ATTN: DRSTE-AD-M (Dr. Norman E. Pentz)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-AAM (Mr. William Smith)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-CS (Mr. Philip H. Beavers)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-GB (Wilbur L. Warfield)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-GP (Mr. Fred Campbell)
Aberdeen Proving Ground, MD 21005

Director
US Army Material Systems Analysis Activity
ATTN: DRXSY-GP (H. Stamper)
Aberdeen Proving Grounds, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-G
(Mr. Michael Starks/Mr. Julian Chernick)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-J (Mr James F. O'Bryon)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-LM (Mr. Robert M. Marchetti)
Aberdeen Proving Ground, MD 21005

Commander
Harry Diamond Laboratories
ATTN: Dr. William W. Carter
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM (Mr. Robert McCoskey)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM-NM (Dr. Robert Humphrey)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM-NM (Dr. Z. G. Sztankay)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM-NM (Dr. Joseph Nemarich)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Air Force Systems Command
ATTN: WER (Mr. Richard F. Picanso)
Andrews AFB, MD 20334

Martin Marietta Laboratories
ATTN: Jar Mo Chen
1450 South Rolling Road
Baltimore, MD 21227

Commander
US Army Concepts Analysis Agency
ATTN: CSCA-SMC (Mr. Hal E. Hock)
8120 Woodmont Avenue
Bethesda, MD 20014

Director
National Security Agency
ATTN: R52/Dr. Douglas Woods
Fort George G. Meade, MD 20755

Chief
Intelligence Materiel Development
& Support Office
US Army Electronic Warfare Laboratory
ATTN: DELEW-I (LTC Kenneth E. Thomas)
Fort George G. Meade, MD 20755

The Johns Hopkins University
Applied Physics Laboratory
ATTN: Dr. Michael J. Lun
John Hopkins Road
Laurell, MD 20810

Dr. Stephen T. Hanley
1720 Rhodesia Avenue
Oxon Hill, MD 20022

Science Applications Inc.
ATTN: Mr. G. D. Currie
15 Research Drive
Ann Arbor, MI 48103

Science Applications Inc.
ATTN: Dr. Robert E. Turner
15 Research Drive
Ann Arbor, MI 48103

Commander
US Army Tank-Automotive Research
& Development Command
ATTN: DRDTA-ZSC (Mr. Harry Young)
Warren, MI 48090

Commander
US Army Tank Automotive Research
& Development Command
ATTN: DRDTA-ZSC (Mr. Wallace Mick, Jr.)
Warren, MI 48090

Dr. A. D. Belmont
Research Division
Control Data Corporation
P.O. Box 1249
Minneapolis, MN 55440

Director
US Army Engr Waterways Experiment Station
ATTN: WESEN (Mr. James Mason)
P.O. Box 631
Vicksburg, MS 39180

Dr. Jerry Davis
Department of Marine, Earth
and Atmospheric Sciences
North Carolina State University
Raleigh, NC 27650

Commander
US Army Research Office
ATTN: DRXRO-GS (Dr. Leo Alpert)
P.O. Box 12211
Research Triangle Park, NC 27709

Commander
US Army Research Office
ATTN: DRXRO-PP (Brenda Mann)
P.O. Box 12211
Research Triangle Park, NC 27709

Commander
US Army Cold Regions Research
& Engineering Laboratory
ATTN: CRREL-RD (Dr. K. F. Sterrett)
Hanover, NH 03755

Commander/Director
US Army Cold Regions Research
& Engineering Laboratory
ATTN: CRREL-RG (Mr. George Aitken)
Hanover, NH 03755

Commander
US Army Cold Regions Research
& Engineering Laboratory
ATTN: CRREL-RG (Mr. Roger H. Berger)
Hanover, NH 03755

Commander
US Army Armament Research
& Development Command
ATTN: DRDAR-AC (Mr. James Greenfield)
Dover, NJ 07801

Commander
US Army Armament Research
& Development Command
ATTN: DRDAR-TSS (Bldg #59)
Dover, NJ 07801

Commander
US Army Armament Research
& Development Command
ATTN: DRCPM-CAWS-EI (Mr. Peteris Jansons)
Dover, NJ 07801

Commander
US Army Armament Research
& Development Command
ATTN: DRCPM-CAWS-EI (Mr. G. H. Waldron)
Dover, NJ 07801

Deputy Joint Project Manager
for Navy/USMC SAL GP
ATTN: DRCPM-CAWS-NV (CPT Joseph Miceli)
Dover, NJ 07801

Commander/Director
US Army Combat Surveillance & Target
Acquisition Laboratory
ATTN: DELCS-I (Mr. David Longinotti)
Fort Monmouth, NJ 07703

Commander/Director
US Army Combat Surveillance & Target
Acquisition Laboratory
ATTN: DELCS-PE (Mr. Ben A. Di Campli)
Fort Monmouth, NJ 07703

Commander/Director
US Army Combat Surveillance & Target
Acquisition Laboratory
ATTN: DELCS-R-S (Mr. Donald L. Foiani)
Fort Monmouth, NJ 07703

Director
US Army Electronics Technology &
Devices Laboratory
ATTN: DELET-DD (S. Danko)
Fort Monmouth, NJ 07703

Project Manager
FIREFINDER/REMBASS
ATTN: DRCPM-FFR-TM (Mr. John M. Bialo)
Fort Monmouth, NJ 07703

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-SA (Dr. Walter S. McAfee)
Fort Monmouth, NJ 07703

OLA, 2WS (MAC)
Holloman AFB, NM 88330

Commander
Air Force Weapons Laboratory
ATTN: AFWL/WE (MAJ John R. Elrick)
Kirtland, AFB, NM 87117

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Dolores Anguiano)
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-TDB (Mr. Louie Dominguez)
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-TDB (Mr. William J. Leach)
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-TGP (Mr. Roger F. Willis)
White Sands Missile Range, NM 88002

Director
Office of Missile Electronic Warfare
ATTN: DELEW-M-STO (Dr. Steven Kovel)
White Sands Missile Range, NM 88002

Office of the Test Director
Joint Services EO GW CM Test Program
ATTN: DRXDE-TD (Mr. Weldon Findley)
White Sands Missile Range, NM 88002

Commander
US Army White Sands Missile Range
ATTN: STEWS-PT-AL (Laurel B. Saunders)
White Sands Missile Range, NM 88002

Commander
US Army R&D Coordinator
US Embassy - Bonn
Box 165
APO New York 09080

Grumman Aerospace Corporation
Research Department - MS A08-35
ATTN: John E. A. Selby
Bethpage, NY 11714

Rome Air Development Center
ATTN: Documents Library
TSLD (Bette Smith)
Griffiss AFB, NY 13441

Dr. Roberto Vaglio-Laurin
Faculty of Arts and Science
Dept. of Applied Science
26-36 Stuyvesant Street
New York, NY 10003

Air Force Wright Aeronautical Laboratories/
Avionics Laboratory
ATTN: AFWAL/AARI-3 (Mr. Harold Geltmacher)
Wright-Patterson AFB, OH 45433

Air Force Wright Aeronautical Laboratories/
Avionics Laboratory
ATTN: AFWAL/AARI-3 (CPT William C. Smith)
Wright-Patterson AFB, OH 45433

Commandant
US Army Field Artillery School
ATTN: ATSF-CF-R (CPT James M. Watson)
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: ATSF-CD-MS
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: ATSF-CF-R
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: NOAA Liaison Officer
(CDR Jeffrey G. Carlen)
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
Morris Swett Library
ATTN: Reference Librarian
Fort Sill, OK 73503

Commander
Naval Air Development Center
ATTN: Code 301 (Mr. George F. Eck)
Warminster, PA 18974

The University of Texas at El Paso
Electrical Engineering Department
ATTN: Dr. Joseph H. Pierluissi
El Paso, TX 79968

Commandant
US Army Air Defense School
ATTN: ATSA-CD-SC-A (CPT Charles T. Thorn)
Fort Bliss, TX 79916

Commander
HQ, TRADOC Combined Arms Test Activity
ATTN: ATCAT-OP-Q (CPT Henry C. Cobb, Jr.)
Fort Hood, TX 76544

Commander
HQ, TRADOC Combined Arms Test Activity
ATTN: ATCAT-SCI (Dr. Darrell W. Collier)
Fort Hood, TX 76544

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-L
Dugway, UT 84022

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-M (Mr. Paul E. Carlson)
Dugway, UT 84022

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-T (Mr. John Trethewey)
Dugway, UT 84022

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-T (Mr. William Peterson)
Dugway, UT 84022

Defense Documentation Center
ATTN: DDC-TCA
Cameron Station Bldg 5
Alexandria, VA 22314
12

Ballistic Missile Defense Program Office
ATTN: DACS-BMT (Colonel Harry F. Ennis)
5001 Eisenhower Avenue
Alexandria, VA 22333

Defense Technical Information Center
ATTN: DDA-2 (Mr. James E. Shafer)
Cameron Station, Bldg 5
Alexandria, VA 22314

Commander
US Army Materiel Development
& Readiness Command
ATTN: DRCBSI-EE (Mr. Albert Giambalvo)
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
US Army Materiel Development
& Readiness Command
ATTN: [illegible] (Mr. James Bender)
5001 Eisenhower Avenue
Alexandria, VA 22333

Defense Advanced Rsch Projects Agency
ATTN: Steve Zakanyez
1400 Wilson Blvd
Arlington, VA 22209

Defense Advanced Rsch Projects Agency
ATTN: Dr. James Tegnelia
1400 Wilson Blvd
Arlington, VA 22209

Institute for Defense Analyses
ATTN: Mr. Lucien M. Biberman
400 Army-Navy Drive
Arlington, VA 22202

Institute for Defense Analyses
ATTN: Dr. Ernest Bauer
400 Army-Navy Drive
Arlington, VA 22202

Institute for Defense Analyses
ATTN: Dr. Hans G. Wolfhard
400 Army-Navy Drive
Arlington, VA 22202

System Planning Corporation
ATTN: Mr. Daniel Friedman
1500 Wilson Boulevard
Arlington, VA 22209

System Planning Corporation
ATTN: COL Hank Shelton
1500 Wilson Boulevard
Arlington, VA 22209

US Army Intelligence & Security Command
ATTN: Edwin Speakman, Scientific Advisor
Arlington Hall Station
Arlington, VA 22212

Commander
US Army Operational Test
& Evaluation Agency
ATTN: CSTE-ED (Mr. Floyd I. Hill)
5600 Columbia Pike
Falls Church, VA 22041

Commander and Director
US Army Engineer Topographic Laboratories
ATTN: ETL-GS-A (Mr. Thomas Neidringhaus)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-L (Dr. Rudolf G. Buser)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-L (Dr. Robert S. Rodhe)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Mr. Joseph R. Moulton)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Luanne P. Obert)
Fort Belvoir, VA 22060

Director
US Army Night Vision
& Electro-Optics Laboratory
ATTN: DELNV-VI (Mr. Thomas W. Cassidy)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Mr. Richard J. Bergemann)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Dr. James A. Ratches)
Fort Belvoir, VA 22060

Commander
US Army Training & Doctrine Command
ATTN: ATCD-AN
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-AN-M
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-F-A (Mr. Chris O'Connor, Jr.)
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-IE-R (Mr. David M. Ingram)
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-M-I/ATCD-M-A
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATDOC-TA (Dr. Marvin P. Pastel)
Fort Monroe, VA 23651

Department of the Air Force
OL-I, AWS
Fort Monroe, VA 23651

Department of the Air Force
HQS 5 Weather Wing (MAC)
ATTN: 5 WW/DN
Langley Air Force Base, VA 23655

Commander
US Army INSCOM/Quest Research Corporation
ATTN: Mr. Donald Wilmot
6845 Elm Street, Suite 407
McLean, VA 22101

General Research Corporation
ATTN: Dr. Ralph Zirkind
7655 Old Springhouse Road
McLean, VA 22102

Science Applications, Inc.
8400 Westpark Drive
ATTN: Dr. John E. Cockayne
McLean, VA 22102

US Army Nuclear & Chemical Agency
ATTN: MONA-WE (Dr. John A. Berberet)
7500 Backlick Road, Bldg 2073
Springfield, VA 22150

Director
US Army Signals Warfare Laboratory
ATTN: DELSW-EA (Mr. Douglas Harkleroad)
Vint Hill Farms Station
Warrenton, VA 22186

Director
US Army Signals Warfare Laboratory
ATTN: DELSW-OS (Dr. Royal H. Burkhardt)
Vint Hill Farms Station
Warrenton, VA 22186

Commander
US Army Cold Regions Test Center
ATTN: STECR-TD (Mr. Jerold Barger)
APO Seattle, WA 98733

HQDA (SAUS-OR/Hunter M. Woodall, Jr./
Dr. Herbert K. Fallin)
Rm 2E 614, Pentagon
Washington, DC 20301

COL Elbert W. Friday, Jr.
OUSDRE
Rm 3D 129, Pentagon
Washington, DC 20301

Defense Communications Agency
Technical Library Center
Code 222
Washington, DC 20305

Director
Defense Nuclear Agency
ATTN: Technical Library (Mrs. Betty Fox)
Washington, DC 20305

Director
Defense Nuclear Agency
ATTN: RAAE (Dr. Carl Fitz)
Washington, DC 20305

Director
Defense Nuclear Agency
ATTN: SPAS (Mr. Donald J. Kohler)
Washington, DC 20305

Defense Intelligence Agency
ATTN: DT/AC (LTC Robert Poplawski)
Washington, DC 20301

HQDA (DAMA-ARZ-D/Dr. Verderame)
Washington, DC 20310

HQDA (DAMI-ISP/Mr. Beck)
Washington, DC 20310

Department of the Army
Deputy Chief of Staff for
Operations and Plans
ATTN: DAMO-RQ
Washington, DC 20310

Department of the Army
Director of Telecommunications and
Command and Control
ATTN: DAMO-TCZ
Washington, DC 20310

Department of the Army
Assistant Chief of Staff for Intelligence
ATTN: DAMI-TS
Washington, DC 20310

HQDA (DAEN-RDM/Dr. de Percin)
Casimir Pulaski Building
20 Massachusetts Avenue
Room 6203
Washington, DC 20314

National Science Foundation
Division of Atmospheric Sciences
ATTN: Dr. Eugene W. Bierly
1800 G. Street, N.W.
Washington, DC 20550

Director
Naval Research Laboratory
ATTN: Code 4320 (Dr. Lothar H. Ruhnke)
Washington, DC 20375

Commanding Officer
Naval Research Laboratory
ATTN: Code 6009 (Dr. John MacCallum, Jr.)
Washington, DC 20375

Commanding Officer
Naval Research Laboratory
ATTN: Code 6530 (Mr. Raymond A. Patten)
Washington, DC 20375

Commanding Officer
Naval Research Laboratory
ATTN: Code 6533 (Dr. James A. Dowling)
Washington, DC 20375

ATMOSPHERIC SCIENCES RESEARCH REPORTS

1. Lindberg, J. D. "An Improvement to a Method for Measuring the Absorption Coefficient of Atmospheric Dust and other Strongly Absorbing Powders," ECOM-5565, July 1975.

2. Avara, Elton P., "Mesoscale Wind Shears Derived from Thermal Winds," ECOM-5566, July 1975.

3. Gomez, Richard B., and Joseph H. Pierluissi, "Incomplete Gamma Function Approximation for King's Strong-Line Transmittance Model," ECOM-5567, July 1975.

4. Blanco, A. J., and B. F. Engebos, "Ballistic Wind Weighting Functions for Tank Projectiles," ECOM-5568, August 1975.

5. Taylor, Fredrick J., Jack Smith, and Thomas H. Pries, "Crosswind Measurements through Pattern Recognition Techniques," ECOM-5569, July 1975.

6. Walters, D. L., "Crosswind Weighting Functions for Direct-Fire Projectiles," ECOM-5570, August 1975.

7. Duncan, Louis D., "An Improved Algorithm for the Iterated Minimal Information Solution for Remote Sounding of Temperature," ECOM-5571, August 1975.

8. Robbiani, Raymond L., "Tactical Field Demonstration of Mobile Weather Radar Set AN/TPS-41 at Fort Rucker, Alabama," ECOM-5572, August 1975.

9. Miers, B., G. Blackman, D. Langer, and N. Lorimier, "Analysis of SMS/GOES Film Data," ECOM-5573, September 1975.

10. Manquero, Carlos, Louis Duncan, and Rufus Bruce, "An Indication from Satellite Measurements of Atmospheric CO_2 Variability," ECOM-5574, September 1975.

11. Petracca, Carmine, and James D. Lindberg, "Installation and Operation of an Atmospheric Particulate Collector," ECOM-5575, September 1975.

12. Avara, Elton P., and George Alexander, "Empirical Investigation of Three Iterative Methods for Inverting the Radiative Transfer Equation," ECOM-5576, October 1975.

13. Alexander, George D., "A Digital Data Acquisition Interface for the SMS Direct Readout Ground Station - Concept and Preliminary Design," ECOM-5577, October 1975.

14. Cantor, Israel, "Enhancement of Point Source Thermal Radiation Under Clouds in a Nonattenuating Medium," ECOM-5578, October 1975.

15. Norton, Colburn, and Glenn Hoidale, "The Diurnal Variation of Mixing Height by Month over White Sands Missile Range, NM," ECOM-5579, November 1975.

16. Avara, Elton P., "On the Spectrum Analysis of Binary Data," ECOM-5580, November 1975.

17. Taylor, Fredrick J., Thomas H. Pries, and Chao-Huan Huang, "Optimal Wind Velocity Estimation," ECOM-5581, December 1975.

18. Avara, Elton P., "Some Effects of Autocorrelated and Cross-Correlated Noise on the Analysis of Variance," ECOM-5582, December 1975.

19. Gillespie, Patti S., R. L. Armstrong, and Kenneth O. White, "The Spectral Characteristics and Atmospheric CO_2 Absorption of the Ho^{+3}:YLF Laser at 2.05μm," ECOM-5583, December 1975.

20. Novlan, David J., "An Empirical Method of Forecasting Thunderstorms for the White Sands Missile Range," ECOM-5584, February 1976.

21. Avara, Elton P., "Randomization Effects in Hypothesis Testing with Autocorrelated Noise," ECOM-5585, February 1976.

22. Watkins, Wendell R., "Improvements in Long Path Absorption Cell Measurement," ECOM-5586, March 1976.

23. Thomas, Joe, George D. Alexander, and Marvin Dubbin, "SATTEL - An Army Dedicated Meteorological Telemetry System," ECOM-5587, March 1976.

24. Kennedy, Bruce W., and Delbert Bynum, "Army User Test Program for the RDT&E-XM-75 Meteorological Rocket," ECOM-5588, April 1976.

25. Barnett, Kenneth M., "A Description of the Artillery Meteorological Comparisons at White Sands Missile Range, October 1974 - December 1974 ('PASS' - Prototype Artillery [Meteorological] Subsystem)," ECOM-5589, April 1976.

26. Miller, Walter B., "Preliminary Analysis of Fall-of-Shot From Project 'PASS'," ECOM-5590, April 1976.

27. Avara, Elton P., "Error Analysis of Minimum Information and Smith's Direct Methods for Inverting the Radiative Transfer Equation," ECOM-5591, April 1976.

28. Yee, Young P., James D. Horn, and George Alexander, "Synoptic Thermal Wind Calculations from Radiosonde Observations Over the Southwestern United States," ECOM-5592, May 1976.

29. Duncan, Louis D., and Mary Ann Seagraves, "Applications of Empirical Corrections to NOAA-4 VTPR Observations," ECOM-5593, May 1976.

30. Miers, Bruce T., and Steve Weaver, "Applications of Meteorological Satellite Data to Weather Sensitive Army Operations," ECOM-5594, May 1976.

31. Sharenow, Moses, "Redesign and Improvement of Balloon ML-566," ECOM-5595, June 1976.

32. Hansen, Frank V., "The Depth of the Surface Boundary Layer," ECOM-5596, June 1976.

33. Pinnick, R. G., and E. B. Stenmark, "Response Calculations for a Commerical Light-Scattering Aerosol Counter," ECOM-5597, July 1976.

34. Mason, J., and G. B. Hoidale, "Visibility as an Estimator of Infrared Transmittance," ECOM-5598, July 1976.

35. Bruce, Rufus E., Louis D. Duncan, and Joseph H. Pierluissi, "Experimental Study of the Relationship Between Radiosonde Temperatures and Radiometric-Area Temperatures," ECOM-5599, August 1976.

36. Duncan, Louis D., "Stratospheric Wind Shear Computed from Satellite Thermal Sounder Measurements," ECOM-5800, September 1976.

37. Taylor, F., P. Mohan, P. Joseph, and T. Pries, "An All Digital Automated Wind Measurement System," ECOM-5801, September 1976.

38. Bruce, Charles, "Development of Spectrophones for CW and Pulsed Radiation Sources," ECOM-5802, September 1976.

39. Duncan, Louis D., and Mary Ann Seagraves, "Another Method for Estimating Clear Column Radiances," ECOM-5803, October 1976.

40. Blanco, Abel J., and Larry E. Taylor, "Artillery Meteorological Analysis of Project Pass," ECOM-5804, October 1976.

41. Miller, Walter, and Bernard Engebos, "A Mathematical Structure for Refinement of Sound Ranging Estimates," ECOM-5805, November 1976.

42. Gillespie, James B., and James D. Lindberg, "A Method to Obtain Diffuse Reflectance Measurements from 1.0 and 3.0μm Using a Cary 17I Spectrophotometer," ECOM-5806, November 1976.

43. Rubio, Roberto, and Robert O. Olsen, "A Study of the Effects of Temperature Variations on Radio Wave Absorption," ECOM-5807, November 1976.

44. Ballard, Harold N., "Temperature Measurements in the Stratosphere from Balloon-Borne Instrument Platforms, 1968-1975," ECOM-5808, December 1976.

45. Monahan, H. H., "An Approach to the Short-Range Prediction of Early Morning Radiation Fog," ECOM-5809, January 1977.

46. Engebos, Bernard Francis, "Introduction to Multiple State Multiple Action Decision Theory and Its Relation to Mixing Structures," ECOM-5810, January 1977.

47. Low, Richard D. H., "Effects of Cloud Particles on Remote Sensing from Space in the 10-Micrometer Infrared Region," ECOM-5811, January 1977.

48. Bonner, Robert S., and R. Newton, "Application of the AN/GVS-5 Laser Rangefinder to Cloud Base Height Measurements," ECOM-5812, February 1977.

49. Rubio, Roberto, "Lidar Detection of Subvisible Reentry Vehicle Erosive Atmospheric Material," ECOM-5813, March 1977.

50. Low, Richard D. H., and J. D. Horn, "Mesoscale Determination of Cloud-Top Height: Problems and Solutions," ECOM-5814, March 1977.

51. Duncan, Louis D., and Mary Ann Seagraves, "Evaluation of the NOAA-4 VTPR Thermal Winds for Nuclear Fallout Predictions," ECOM-5815, March 1977.

52. Randhawa, Jagir S., M. Izquierdo, Carlos McDonald, and Zvi Salpeter, "Stratospheric Ozone Density as Measured by a Chemiluminescent Sensor During the Stratcom VI-A Flight," ECOM-5816, April 1977.

53. Rubio, Roberto, and Mike Izquierdo, "Measurements of Net Atmospheric Irradiance in the 0.7- to 2.8-Micrometer Infrared Region," ECOM-5817, May 1977.

54. Ballard, Harold N., Jose M. Serna, and Frank P. Hudson, Consultant for Chemical Kinetics, "Calculation of Selected Atmospheric Composition Parameters for the Mid-Latitude, September Stratosphere," ECOM-5818, May 1977.

55. Mitchell, J. D., R. S. Sagar, and R. O. Olsen, "Positive Ions in the Middle Atmosphere During Sunrise Conditions," ECOM-5819, May 1977.

56. White, Kenneth O., Wendell R. Watkins, Stuart A. Schleusener, and Ronald L. Johnson, "Solid-State Laser Wavelength Identification Using a Reference Absorber," ECOM-5820, June 1977.

57. Watkins, Wendell R., and Richard G. Dixon, "Automation of Long-Path Absorption Cell Measurements," ECOM-5821, June 1977.

58. Taylor, S. E., J. M. Davis, and J. B. Mason, "Analysis of Observed Soil Skin Moisture Effects on Reflectance," ECOM-5822, June 1977.

59. Duncan, Louis D., and Mary Ann Seagraves, "Fallout Predictions Computed from Satellite Derived Winds," ECOM-5823, June 1977.

60. Snider, D. E., D. G. Murcray, F. H. Murcray, and W. J. Williams, "Investigation of High-Altitude Enhanced Infrared Backround Emissions," (U), SECRET, ECOM-5824, June 1977.

61. Dubbin, Marvin H., and Dennis Hall, "Synchronous Meteorological Satellite Direct Readout Ground System Digital Video Electronics," ECOM-5825, June 1977.

62. Miller, W., and B. Engebos, "A Preliminary Analysis of Two Sound Ranging Algorithms," ECOM-5826, July 1977.

63. Kennedy, Bruce W., and James K. Luers, "Ballistic Sphere Techniques for Measuring Atmospheric Parameters," ECOM-5827, July 1977.

64. Duncan, Louis D., "Zenith Angle Variation of Satellite Thermal Sounder Measurements," ECOM-5828, August 1977.

65. Hansen, Frank V., "The Critical Richardson Number," ECOM-5829, September 1977.

66. Ballard, Harold N., and Frank P. Hudson (Compilers), "Stratospheric Composition Balloon-Borne Experiment," ECOM-5830, October 1977.

67. Barr, William C., and Arnold C. Peterson, "Wind Measuring Accuracy Test of Meteorological Systems," ECOM-5831, November 1977.

68. Ethridge, G. A., and F. V. Hansen, "Atmospheric Diffusion: Similarity Theory and Empirical Derivations for Use in Boundary Layer Diffusion Problems," ECOM-5832, November 1977.

69. Low, Richard D. H., "The Internal Cloud Radiation Field and a Technique for Determining Cloud Blackness," ECOM-5833, December 1977.

70. Watkins, Wendell R., Kenneth O. White, Charles W. Bruce, Donald L. Walters, and James D. Lindberg, "Measurements Required for Prediction of High Energy Laser Transmission," ECOM-5834, December 1977.

71. Rubio, Robert, "Investigation of Abrupt Decreases in Atmospherically Backscattered Laser Energy," ECOM-5835, December 1977.

72. Monahan, H. H., and R. M. Cionco, "An Interpretative Review of Existing Capabilities for Measuring and Forecasting Selected Weather Variables (Emphasizing Remote Means)," ASL-TR-0001, January 1978.

73. Heaps, Melvin G., "The 1979 Solar Eclipse and Validation of D-Region Models," ASL-TR-0002, March 1978.

74. Jennings, S. G., and J. B. Gillespie, "M.I.E. Theory Sensitivity Studies - The Effects of Aerosol Complex Refractive Index and Size Distribution Variations on Extinction and Absorption Coefficients, Part II: Analysis of the Computational Results," ASL-TR-0003, March 1978.

75. White, Kenneth O., et al, "Water Vapor Continuum Absorption in the 3.5μm to 4.0μm Region," ASL-TR-0004, March 1978.

76. Olsen, Robert O., and Bruce W. Kennedy, "ABRES Pretest Atmospheric Measurements," ASL-TR-0005, April 1978.

77. Ballard, Harold N., Jose M. Serna, and Frank P. Hudson, "Calculation of Atmospheric Composition in the High Latitude September Stratosphere," ASL-TR-0006, May 1978.

78. Watkins, Wendell R., et al, "Water Vapor Absorption Coefficients at HF Laser Wavelengths," ASL-TR-0007, May 1978.

79. Hansen, Frank V., "The Growth and Prediction of Nocturnal Inversions," ASL-TR-0008, May 1978.

80. Samuel, Christine, Charles Bruce, and Ralph Brewer, "Spectrophone Analysis of Gas Samples Obtained at Field Site," ASL-TR-0009, June 1978.

81. Pinnick, R. G., et al., "Vertical Structure in Atmospheric Fog and Haze and its Effects on IR Extinction," ASL-TR-0010, July 1978.

82. Low, Richard D. H., Louis D. Duncan, and Richard B. Gomez, "The Microphysical Basis of Fog Optical Characterization," ASL-TR-0011, August 1978.

83. Heaps, Melvin G., "The Effect of a Solar Proton Event on the Minor Neutral Constituents of the Summer Polar Mesosphere," ASL-TR-0012, August 1978.

84. Mason, James B., "Light Attenuation in Falling Snow," ASL-TR-0013, August 1978.

85. Blanco, Abel J., "Long-Range Artillery Sound Ranging: 'PASS' Meteorological Application," ASL-TR-0014, September 1978.

86. Heaps, M. G., and F. E. Niles, "Modeling of Ion Chemistry of the D-Region: A Case Study Based Upon the 1966 Total Solar Eclipse," ASL-TR-0015, September 1978.

87. Jennings, S. G., and R. G. Pinnick, "Effects of Particulate Complex Refractive Index and Particle Size Distribution Variations on Atmospheric Extinction and Absorption for Visible Through Middle-Infrared Wavelengths," ASL-TR-0016, September 1978.

88. Watkins, Wendell R., Kenneth O. White, Lanny R. Bower, and Brian Z. Sojka, "Pressure Dependence of the Water Vapor Continuum Absorption in the 3.5- to 4.0-Micrometer Region," ASL-TR-0017, September 1978.

89. Miller, W. B., and B. F. Engebos, "Behavior of Four Sound Ranging Techniques in an Idealized Physical Environment," ASL-TR-0018, September 1978.

90. Gomez, Richard G., "Effectiveness Studies of the CBU-88/B Bomb, Cluster, Smoke Weapon," (U), CONFIDENTIAL ASL-TR-0019, September 1978.

91. Miller, August, Richard C. Shirkey, and Mary Ann Seagraves, "Calculation of Thermal Emission from Aerosols Using the Doubling Technique," ASL-TR-0020, November 1978.

92. Lindberg, James D., et al, "Measured Effects of Battlefield Dust and Smoke on Visible, Infrared, and Millimeter Wavelengths Propagation: A Preliminary Report on Dusty Infrared Test-I (DIRT-I)," ASL-TR-0021, January 1979.

93. Kennedy, Bruce W., Arthur Kinghorn, and B. R. Hixon, "Engineering Flight Tests of Range Meteorological Sounding System Radiosonde," ASL-TR-0022, February 1979.

94. Rubio, Roberto, and Don Hoock, "Microwave Effective Earth Radius Factor Variability at Wiesbaden and Balboa," ASL-TR-0023, February 1979.

95. Low, Richard D. H., "A Theoretical Investigation of Cloud/Fog Optical Properties and Their Spectral Correlations, "ASL-TR-0024, February 1979.

96. Pinnick, R. G., and H. J. Auvermann, "Response Characteristics of Knollenberg Light-Scattering Aerosol Counters," ASL-TR-0025, February 1979.

97. Heaps, Melvin G., Robert O. Olsen, and Warren W. Berning, "Solar Eclipse 1979, Atmospheric Sciences Laboratory Program Overview," ASL-TR-0026, February 1979.

98. Blanco, Abel J., "Long-Range Artillery Sound Ranging: 'PASS' GR-8 Sound Ranging Data," ASL-TR-0027, March 1979.

99. Kennedy, Bruce W., and Jose M. Serna, "Meteorological Rocket Network System Reliability," ASL-TR-0028, March 1979.

100. Swingle, Donald M., "Effects of Arrival Time Errors in Weighted Range Equation Solutions for Linear Base Sound Ranging," ASL-TR-0029, April 1979.

101. Umstead, Robert K., Ricardo Pena, and Frank V. Hansen, "KWIK: An Algorithm for Calculating Munition Expenditures for Smoke Screening/Obscuration in Tactical Situations," ASL-TR-0030, April 1979.

102. D'Arcy, Edward M., "Accuracy Validation of the Modified Nike Hercules Radar," ASL-TR-0031, May 1979.

103. Rodriguez, Ruben, "Evaluation of the Passive Remote Crosswind Sensor," ASL-TR-0032, May 1979.

104. Barber, T. L., and R. Rodriguez, "Transit Time Lidar Measurement of Near-Surface Winds in the Atmosphere," ASL-TR-0033, May 1979.

105. Low, Richard D. H., Louis D. Duncan, and Y. Y. Roger R. Hsiao, "Microphysical and Optical Properties of California Coastal Fogs at Fort Ord," ASL-TR-0034, June 1979.

106. Rodriguez, Ruben, and William J. Vechione, "Evaluation of the Saturation Resistant Crosswind Sensor," ASL-TR-0035, July 1979.

107. Ohmstede, William D., "The Dynamics of Material Layers," ASL-TR-0036, July 1979.

108. Pinnick, R. G., S. G. Jennings, Petr Chylek, and H. J. Auvermann, "Relationships between IR Extinction Absorption, and Liquid Water Content of Fogs," ASL-TR-0037, August 1979.

109. Rodriguez, Ruben, and William J. Vechione, "Performance Evaluation of the Optical Crosswind Profiler," ASL-TR-0038, August 1979.

110. Miers, Bruce T., "Precipitation Estimation Using Satellite Data," ASL-TR-0039, September 1979.

111. Dickson, David H., and Charles M. Sonnenschein, "Helicopter Remote Wind Sensor System Description," ASL-TR-0040, September 1979.

112. Heaps, Melvin G., and Joseph M. Heimerl, "Validation of the Dairchem Code, I: Quiet Midlatitude Conditions," ASL-TR-0041, September 1979.

113. Bonner, Robert S., and William J. Lentz, "The Visioceilometer: A Portable Cloud Height and Visibility Indicator," ASL-TR-0042, October 1979.

114. Cohn, Stephen L., "The Role of Atmospheric Sulfates in Battlefield Obscurations," ASL-TR-0043, October 1979.

115. Fawbush, E. J., et al, "Characterization of Atmospheric Conditions at the High Energy Laser System Test Facility (HELSTF), White Sands Missile Range, New Mexico, Part I, 24 March to 8 April 1977," ASL-TR-0044, November 1979.

116. Barber, Ted L., "Short-Time Mass Variation in Natural Atmospheric Dust," ASL-TR-0045, November 1979.

117. Low, Richard D. H., "Fog Evolution in the Visible and Infrared Spectral Regions and its Meaning in Optical Modeling," ASL-TR-0046, December 1979.

118. Duncan, Louis D., et al, "The Electro-Optical Systems Atmospheric Effects Library, Volume I: Technical Documentation," ASL-TR-0047, December 1979.

119. Shirkey, R. C., et al, "Interim E-O SAEL, Volume II, Users Manual," ASL-TR-0048, December 1979.

120. Kobayashi, H. K., "Atmospheric Effects on Millimeter Radio Waves," ASL-TR-0049, January 1980.

121. Seagraves, Mary Ann, and Louis D. Duncan, "An Analysis of Transmittances Measured Through Battlefield Dust Clouds," ASL-TR-0050, February 1980.

122. Dickson, David H., and Jon E. Ottesen, "Helicopter Remote Wind Sensor Flight Test," ASL-TR-0051, February 1980.

123. Pinnick, R. G., and S. G. Jennings, "Relationships Between Radiative Properties and Mass Content of Phosphoric Acid, HC, Petroleum Oil, and Sulfuric Acid Military Smokes," ASL-TR-0052, April 1980.

124. Hinds, B. D., and J. B. Gillespie, "Optical Characterization of Atmospheric Particulates on San Nicolas Island, California," ASL-TR-0053, April 1980.

125. Miers, Bruce T., "Precipitation Estimation for Military Hydrology," ASL-TR-0054, April 1980.

126. Stenmark, Ernest B., "Objective Quality Control of Artillery Computer Meteorological Messages," ASL-TR-0055, April 1980.

127. Duncan, Louis D., and Richard D. H. Low, "Bimodal Size Distribution Models for Fogs at Meppen, Germany," ASL-TR-0056, April 1980.

128. Olsen, Robert O., and Jagir S. Randhawa, "The Influence of Atmospheric Dynamics on Ozone and Temperature Structure," ASL-TR-0057, May 1980.

129. Kennedy, Bruce W., et al, "Dusty Infrared Test-II (DIRT-II) Program," ASL-TR-0058, May 1980.

130. Heaps, Melvin G., Robert O. Olsen, Warren Berning, John Cross, and Arthur Gilcrease, "1979 Solar Eclipse, Part I - Atmospheric Sciences Laboratory Field Program Summary," ASL-TR-0059, May 1980

131. Miller, Walter B., "User's Guide for Passive Target Acquisition Program Two (PTAP-2)," ASL-TR-0060, June 1980.

132. Holt, E. H., editor, "Atmospheric Data Requirements for Battlefield Obscuration Applications," ASL-TR-0061, June 1980.

133. Shirkey, Richard C., August Miller, George H. Goedecke, and Yugal Behl, "Single Scattering Code AGAUSX: Theory, Applications, Comparisons, and Listing," ASL-TR-0062, July 1980.

134. Sojka, Brian Z., and Kenneth O. White, "Evaluation of Specialized Photoacoustic Absorption Chambers for Near-Millimeter Wave (NMMW) Propagation Measurements," ASL-TR-0063, August 1980.

135. Bruce, Charles W., Young Paul Yee, and S. G. Jennings, "In Situ Measurement of the Ratio of Aerosol Absorption to Extinction Coefficient," ASL-TR-0064, August 1980.

136. Yee, Young Paul, Charles W. Bruce, and Ralph J. Brewer, "Gaseous/Particulate Absorption Studies at WSMR using Laser Sourced Spectrophones," ASL-TR-0065, June 1980.

137. Lindberg, James D., Radon B. Loveland, Melvin Heaps, James B. Gillespie, and Andrew F. Lewis, "Battlefield Dust and Atmospheric Characterization Measurements During West German Summertime Conditions in Support of Grafenwohr Tests," ASL-TR-0066, September 1980.

138. Vechione, W. J., "Evaluation of the Environmental Instruments, Incorporated Series 200 Dual Component Wind Set," ASL-TR-0067, September 1980.

139. Bruce, C. W., Y. P. Yee, B. D. Hinds, R. G. Pinnick, R. J. Brewer, and J. Minjares, "Initial Field Measurements of Atmospheric Absorption at 9μm to 11μm Wavelengths," ASL-TR-0068, October 1980.

140. Heaps, M. G., R. O. Olsen, K. D. Baker, D. A. Burt, L. C. Howlett, L. L. Jensen, E. F. Pound, and G. D. Allred, "1979 Solar Eclipse: Part II Initial Results for Ionization Sources, Electron Density, and Minor Neutral Constituents," ASL-TR-0069, October 1980.

141. Low, Richard D. H., "One-Dimensional Cloud Microphysical Models for Central Europe and their Optical Properties," ASL-TR-0070, October 1980.

142. Duncan, Louis D., James D. Lindberg, and Radon B. Loveland, "An Empirical Model of the Vertical Structure of German Fogs," ASL-TR-0071, November 1980.

143. Duncan, Louis D., 1981, "EOSAEL 80, Volume I, Technical Documentation," ASL-TR-0072, January 1981.

144. Shirkey, R. C., and S. G. O'Brien, "EOSAEL 80, Volume II, Users Manual," ASL-TR-0073, January 1981.

145. Bruce, C. W., "Characterization of Aerosol Nonlinear Effects on a High-Power CO_2 Laser Beam," ASL-TR-0074, February 1981.

146. Duncan, Louis D., and James D. Lindberg, "Air Mass Considerations in Fog Optical Modeling," ASL-TR-0075, February 1981.

147. Kunkel, Kenneth E., "Evaluation of a Tethered Kite Anemometer," ASL-TR-0076, February 1981.

148. Kunkel, K. E., et al, "Characterization of Atmospheric Conditions at the High Energy Laser System Test Facility (HELSTF) White Sands Missile Range, New Mexico, August 1977 to October 1978, Part II, Optical Turbulence, Wind, Water Vapor Pressure, Temperature," ASL-TR-0077, February 1981.

149. Miers, Bruce T., "Weather Scenarios for Central Germany," ASL-TR-0078, February 1981.

150. Cogan, James L., "Sensitivity Analysis of a Mesoscale Moisture Model," ASL-TR-0079, March 1981.

151. Brewer, R. J., C. W. Bruce, and J. L. Mater, "Optoacoustic Spectroscopy of C_2H_4 at the 9μm and 10μm $C^{12}O_2^{16}$ Laser Wavelengths," ASL-TR-0080, March 1981.

152. Swingle, Donald M., "Reducible Errors in the Artillery Sound Ranging Solution, Part I: The Curvature Correction" (U), SECRET, ASL-TR-0081, April 1981.

153. Miller, Walter B., "The Existence and Implications of a Fundamental System of Linear Equations in Sound Ranging" (U), SECRET, ASL-TR-0082, April 1981.

154. Bruce, Dorothy, Charles W. Bruce, and Young Paul Yee, "Experimentally Determined Relationship Between Extinction and Liquid Water Content," ASL-TR-0083, April 1981.

155. Seagraves, Mary Ann, "Visible and Infrared Obscuration Effects of Ice Fog," ASL-TR-0084, May 1981.

156. Watkins, Wendell R., and Kenneth O. White, "Wedge Absorption Remote Sensor," ASL-TR-0085, May 1981.

157. Watkins, Wendell R., Kenneth O. White, and Laura J. Crow, "Turbulence Effects on Open Air Multipaths," ASL-TR-0086, May 1981.

158. Blanco, Abel J., "Extending Application of the Artillery Computer Meteorological Message," ASL-TR-0087, May 1981.

159. Heaps, M. G., D. W. Hoock, R. O. Olsen, B. F. Engebos, and R. Rubio, "High Frequency Position Location: An Assessment of Limitations and Potential Improvements," ASL-TR-0088, May 1981.

160. Watkins, Wendell R., and Kenneth O. White, "Laboratory Facility for Measurement of Hot Gaseous Plume Radiative Transfer," ASL-TR-0089, June 1981.

161. Heaps, M. G., "Dust Cloud Models: Sensitivity of Calculated Transmittances to Variations in Input Parameters. ASL-TR-0090, June 1981.

162. Seagraves, Mary Ann, "Some Optical Properties of Blowing Snow," ASL-TR-0091, June 1981.

163. Kobayashi, Herbert K., "Effect of Hail, Snow, and Melting Hydrometeors on Millimeter Radio Waves," ASL-TR-0092, July 1981.